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Effect of corn tillage system on physical properties of the soil and on bio-factors of plants

Pablo Rangel H.
Iowa State University

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by

Pablo O. Rangel H.

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INTRODUCTION

Corn (Zea mays L.) is the most valuable crop in the United States and is grown on more acres than any other harvested crop. Crop production in the United States centers in the north central states and has more than doubled in the last 30 years, rising from 2.1 to 5.5 billion bushels. In 1970, United States corn production accounted for 48% of the total world output (74).

Tillage is one of the oldest practices in the production of crops; it has been used by man since ancient times. Although rapid advances have been made during the last century, it is still far from an exact science. Farmers must still guess at the amount of tillage to employ for seedbed preparation and cultivation. The use of tillage tools has been and is still being governed largely by estimation based on past experiences (50).

Many of the principles of good tillage practice have been handed down from generation to generation and only over the past three decades have various sciences been applied to the practice of tillage. Thus, agronomists and agricultural engineers with the farmers have become more concerned about the complexity of the tillage process and knowledge of soil. They are seeking the needed physical manipulation of soil to increase production and decrease erosion.

Many research programs have been in progress throughout the corn belt for a number of years on the development and use of machinery in tillage practices for corn production. Frequently, crop responses to tillage varied among years and among locations. Soil and weather vary widely, and tillage practices that are satisfactory on one soil under one weather condition may not be effective under other soil or weather conditions. Corn also responds to variations of soil water, soil temperature, soil air, and soil impedance. The purpose of tillage is to alter the tilth or fabric of the soil so that water, air, temperature, and strength conditions in the soil are improved for plant growth and for the long-time productivity of the soil (47).

Major reasons for tillage are reduction of bulk density, weed control, seedbed preparation, crop residue management, fertilizer placement, soil aeration, wind and water erosion control and changes in cropping systems (Currence, 23).

Known methods and new methods of evaluating soil parameters for describing soil conditions created by tillage and their relation to plant growth should be directly applied to tillage studies to show what physical conditions are needed and how to create those conditions for optimum crop production.

The investigations have been presented here in two main parts. The first part deals with the influence of corn tillage system on physical properties of soil. In the second part, the bio-factors of plants associated with the corn tillage systems have been measured and were related to their effect on yield.

OBJECTIVES

The objectives of this study are as follows:

General Objectives

To study the effect of corn tillage system on physical properties of the soil and on bio-factors of plants.

Specific Objectives

The specific objectives are as follow:

1. To determine the influence of corn tillage systems on the bulk density and moisture content.
2. To determine the influence of corn tillage systems on the cone index of the soil.
3. To determine the influence of corn tillage systems on cohesion and angle of internal friction of the soil.
4. To determine the effects of corn tillage operations on the bio-factors such as height of plants, stand count, weed control, corn moisture at harvest and corn yields.

REVIEW OF LITERATURE

An early eighteenth century English farmer, Jethro Tull, is noted by his revolutionary ideas of horse-hoeing. In the same century a wide variety of horse-drawn implements was developed. Important changes in plow design were brought about by theorists like James Small and Arbuthnot as cited in Partridge (59). One of the best known earlier assumptions as to the reason for tillage was made by Jethro Tull. He said that tillage improved the productivity of soil because it caused a breaking down of the large soil particles into smaller ones which increased the surface from which plant roots obtained their food as cited in Baver (11). The plow is discussed at some length in an interesting and instructive treatise, "On Horse Hoeing Husbandry" written by Jethro Tull in 1733. Tull's conception of the purpose of plowing and cultivation was in part erroneous, but his book served to call attention to the importance of these operations in improving the productivity of the soil as cited in Bear (12).

The tillage operations have been improved since Tull's day and the research work is now more efficiently done. Considerable attention has been given to bringing the science of tillage to a level where it can be compared with the chemical and biological aspects of soil science (44). Considerable space has been devoted in early literature on soil tillage to discussion of why plowing or other mechanical manipulation of the soil increased yield (42).

Baver (11) was concerned about manipulation of soil and stated the problem of soil manipulation is of a biological and dynamic nature.

Biologically, it requires fundamental knowledge about the requirements of different plants on different soils relative to the physical conditions of the soil that is most favorable for plant growth. From the dynamic point of view, tillage operations must be analyzed as to the various physical processes that take place within the soil, in regard to their effects of the nature of the tillage operation as well as the influence of certain tillage practices upon the activity of certain of these processes. Also, other factors, such as compaction and erosion, soil type and aggregates, moisture content and seedling emergency, etc. are equally as interrelated.

The main goal of tillage according to H. Kohnke (40) is to bring about a soil structure that is beneficial for plant growth. This includes a firm seedbed in the planting rows with good capillary contact to the subsoil, and a fairly loose structure in the soil between the rows. This allows for ample infiltration and aeration, yet prevents excessive loss of water by evaporation.

Gill and Vanden Berg (33) wrote that the ultimate aim of tillage is to manipulate a soil from a known condition into a different desired condition by mechanical means. Also, according to Gill and Vanden Berg, the objective of the mechanics of tillage tools is to provide a method for describing the application of forces to the soil and for describing the soil's reaction to the forces. A better understanding of tillage mechanics would provide a method by which the effects could be predicted and controlled by the design of a tillage tool or by the use of a sequence of tillage tools.

Larson (45) emphasized the need for soil tillage. He cited several examples of tillage effects on crop yields, water intake, water-use patterns, and wind and soil erosion. Larson felt that the causative factors and interactions are, in most instances, poorly understood. He also recognized that the failure to distinguish seedbed, or row zone, from the interrow zone in terms of management requirements has also impaired the understanding of tillage and soil structure. Larson (46) studied soil parameters for evaluating tillage requirements for corn. These parameters for corn were soil temperature, secondary aggregate size, bulk density, volume of the zone, depression storage, plow layer storage and surface mulch or surface micro relief. He also pointed out that secondary aggregate size and geometrical arrangement is one of the most important soil parameters in considering management of the row zone where seed germination and early plant growth occur.

Considerable work has been done to obtain the influence that weather has on crop response to tillage (10, 17, 19, 53, 44, 76). Thompson (72) separated weather effects from technology effects on corn production. He used a multiple regression analysis in order to separate the technology effects. He found that July rainfall and August temperature were the two most important effects. Holt et al. (34) recognized the importance of stored soil moisture to the growth of corn in eastern South Dakota and western Minnesota. Larson (44) expressed the influence that tillage has on the soil water available for crop growth.

Johnson and Buchele reported in 1961 (37) that an increased evaporation rate as aggregate size increased from 1.2 to 8.5 mm. They conducted experiments to study the effect of varying soil granule size and compaction on rate of drying. Though these experiments were not directly concerned with tillage operations, the results may be used to supply an indication of the effects of dynamic factors related to tillage on rate of drying. They found that as granule size increases, the rate of soil drying also increases. Infiltration of water into, and evaporation out of soil profile can be modified by changing the size distribution in tilled layer (4). In 1965 Allmaras et al. (6) reported the extent to which these parameters can be modified by tillage.

Moldenhauer et al. (54) conducted experiments to compare three tillage methods for their effectiveness in controlling soil and water losses with up-and-down hill planting on a range of slopes from 3.4 to 9% using a rotating-boom rainfall simulator. Following are conclusions taken from this study.

1. System of ridges with mulched furrows reduced erosion 80% compared with a conventional tilled system.
2. On plots with simulated rainfall, slopes had little effect on the total runoff for ridges.
3. The ridged plots had slightly higher runoff volumes indicating that the ridges shedded the water into the furrows which in effect reduced the area available for infiltration of water. (The impoundment feature of ridges was inoperative in the up-and-down hill rows.)

Many investigations have been made on crop response to tillage practices as well as to aid in describing a desirable environment for plant growth. Literature was reviewed for bulk density, soil moisture, soil strength, weed control and plant population.

Bulk Density

It has been known that the manipulation of soil by tillage practices changes the bulk density of the soil. Alderfer and Merkle (3) studied the alterations in bulk density due to tillage. Richard and Wadleigh (61) pointed out that the changes of bulk density created by tillage practices influence the void-solid relationship and they modify the consistency of the soil and its capacity to conduct and retain water, air and heat.

Buchele (18) developed a power sampler of undisturbed soil to investigate its use in physical measurements made on undisturbed soil cores.

Kuipers (43) was one of the first researchers in the agricultural field to investigate the use of soil surface profile to study the change in bulk density. He developed a relief meter which measured the heights of the soil surface to a datum line. Luttrell (50) used the relief meter for bulk density determination. He used a profile meter developed to facilitate the collecting and recording of soil surface data automatically.

Phillips (60) used for bulk density determination an undisturbed soil cores taken with a power-driven core sampler developed by Buchele (18). By the use of this sampler it was possible to take an undisturbed soil cylinder 3 inches in diameter and 18 inches long. Currence (23) used the same motor driven, soil core sampler to obtain undisturbed soil samples. Smith et al. (68) presented a method to make "in situ" measurement of bulk density and its response to a change in soil porosity.

Diebold (24) studied the effect of tillage practices upon intake rates and runoff. He found that when the bulk density was 1.17 g per cc, the infiltration rate was 4.7 inches per hour. When the bulk density reached 1.49 g per cc, the infiltration rate was 1.2 inches per hour. These alterations in the bulk density can have effect on the soil moisture.

Compaction or the increasing of soil bulk density by the reduction of pore space between the soil particles can produce a deterioration of the soil structure. In tilled zone, the deterioration of structure can create soil crusting, reduction of pore space and compact layers or hardpans.

Lemos and Lutz (48) found that natural soil crust created through soil genesis had a greater bulk density than underlying soil.

Aggregation of soil particles is an important factor in the elimination of conditions of crusting and compact zones.

Luttrell's (50) results of tillage studies indicated that bulk density, clod size, and surface roughness correlated with each other.

Soane (69) investigated a gamma-ray transmission method for the measurement of bulk density in field tillage studies. The results showed that the method is satisfactory for measurement of the abrupt changes in soil bulk density which can occur in field tillage studies.

Soil Moisture

Soil moisture plays an important part in determining tillage machinery performance. The moisture in the soil is one of its most important components. It is a very important factor in determining the nature of the soil and the properties and processes that govern plant growth. Soil moisture is, in addition, a highly important agricultural factor. Controlling water conditions in the soil is always an important technique in improving the productivity of agricultural land.

The functions of soil in respect to the growth of higher plants are to supply the necessary mineral nutrients, water, and oxygen and to provide the environment for the elaboration of the root system that absorbs these substances and anchors the aerial parts (14). According to Kirkham and Powers (39), to understand the physical behavior of water in soil we need a mental picture of the water molecule. They also write that the main reason for investigating the structure of water is to help explain its interaction with soil particles.

Kohnke (40) shows that a soil should only be tilled when its structure is improved by such an operation; when the soil is too wet, it is puddle by tillage. When it is too dry, it has such a high degree of cohesion that it breaks into large clods and powder, so that structure suffers. He also said that very important soil-moisture condition is estimated to fall between pF 2.8 and 4.4. He indicates the pF of 2.8 as the wet limit of best tillage. The pF function is defined as the logarithm to the base 10 of the numerical value of the negative pressure of the soil moisture expressed in centimeters of water.

According to Schwab et al. (64) simplest classification of soil moisture includes three categories:

1. Hygroscopic moisture: Water held tightly to the surface of soil particles by absorption forces.
2. Capillary moisture: Water held by forces of surface tension as continuous films around particles and in the capillary spaces.
3. Gravitational moisture: Water that moves freely in response to gravity and drains out of the soil.

Furr and Reeve (30) classified soil moisture into the following categories as affects availability for plant uptake:

1. Soil moisture available for vegetative growth: that moisture held between field capacity and the permanent wilting percentage.
2. Soil moisture available to sustain life: that held between the permanent wilting percentage and the ultimate wilting percentage.
3. Soil moisture completely unavailable to plants: that moisture held at tensions higher than the ultimate wilting percentage.

Kohnke (40) presented a practical classification of soil water by dividing it into the conditions in which it exists. He makes the relationships between the various dimensions expressing soil-moisture tension and the soil moisture constant:

Water constitution and inter-layer water	Above pF 7
Hygroscopic water	pF 7-4.5
Capillary water	pF 4.5-2.5
Gravitational water	pF 2.5-0
Groundwater	Tension free

The traditional method to determine moisture content of soil is to weigh it before and after oven-drying at 105° C. Soil moisture content is expressed as the moisture percentage based on oven-dry weight. Some direct and indirect methods for measuring soil moisture are presented by Gardner (31).

Shaw et al. (67) wrote that soil moisture measurements have been made by numerous devices and techniques. These can be classified into three groups: (a) point samples such as that measured by the Bouyoucos blocks, (b) line sample such as that measured by the Veihmeyer or King soil sampling tube, (c) volume sample such as that measured by the neutron moisture meter. The neutron moisture meter is a device which has been used to determine the measurements of moisture change in the soil (38).

Luttrell (50) studied the effect of the combination and sequence of various tillage systems. These studies were conducted on three different kinds of soil and no conclusive results were reached by soil type or moisture content.

Soil Strength

An understanding of the mechanical properties of the soil under tillage practice is essential for optimum selection and utilization of the practices.

The variations of mechanical properties of soil exert a physical resistance effect on the growing root and on the environmental requirements of germination such as moisture and gas exchange. Bradford (16) pointed out that a change in the mechanical properties will alter the aeration, water, and thermal properties of the soil, which in turn affect the plants response. He also pointed out that it is usually difficult to determine the specific effects of mechanical impedance upon root growth because the aeration, water, and thermal properties of the soil are interdependent.

The effects of physical impedance are severe when soil had been compacted while moist and then dried. Donahue et al. (25) define engineering compaction as any process by which the soil grains are rearranged to decrease void space and bring them into closer contact with one another, thereby increasing the weight of bulk material per cubic foot. A major effect of soil compaction is an increase in soil strength which results in increased physical impedance to subterranean plant growth. As soil strength increases, the plant correspondingly must exert more pressure to extend its growth through the soil. Aeration and moisture availability are also affected by a reduction of pore space resulting from compaction (41).

Extensive work has been done on the subject of soil compaction and associated plant responses. Phillips (60) performed laboratory experiments to study the growth of corn seedlings. His conclusions were as follows:

1. Bulk density and needle penetrability limit growth and elongation of roots.
2. Needle penetrability is a slightly more sensitive indicator of mechanical impedance of soil than is bulk density.
3. Needle penetration is a more sensitive index to final yields than is bulk density.

The responses of plants to the effects of high soil compaction were studied by Rosenberg, Floker et al., Phillips and Kirkham, Barley et al., and others as quoted by Kollman (41).

Gill and Miller (32) observed on the root growth of corn seedling a pronounced interaction of mechanical impedance and aeration.

Bowen (15) studied 18 different situations affecting cotton seed germination and emergence. The following conclusions were taken from his study:

1. Histories of only four variables were adequate to permit a

prediction of the general degree of emergence resulting from various combinations of surface compaction and soil moisture content at planting.

2. A unique physical environment resulted from each combination of soil moisture content, surface compaction at planting, and weather pattern following planting.
3. A wide range in subsequent physical environmental histories could be produced by simply varying moisture content and surface compaction at the time of planting.
4. The effects of planting operations on the physical environment were clearly evident throughout the period of emergence.
5. A stress of any kind increased the time for emergence of the seedling.

Kollman (41) investigated the effects on soil compaction on weed seedling emergence under controlled laboratory conditions. Experimental variables were bulk density, soil moisture level, temperature, planting depth, planting density, and weed species. This physical resistance of the soil is a major cause of reduced seedling emergence from compacted soil.

Jensen (36) performed a field experiment to evaluate the soybean growth and yield under two levels of applied compaction and irrigation of the soil. Accompanying measurements of soil moisture, soil aeration, and soil bulk density were made to aid in the evaluation of the results. The following conclusions were drawn from his experiment:

1. Compaction of the soil decreased the plant height and average seed weight throughout the soil moisture range.

2. The increase in growth resulting from irrigation was largely independent of the decrease of growth by soil compaction.

Aldabagh (2) studied the effect of tile drainage on trafficability of soil and mobility of agricultural equipment. This purpose was achieved by first relating the performance of vehicles to soil strength in terms of rating cone index. The rating cone index was evaluated by the cone penetrometer and remolding equipment. Relations were developed between soil strength, moisture content, and depth to water table for poorly drained soil.

Recording penetrometer has been used in evaluating of strength properties of soil. McClelland (51) developed a penetrometer to measure the horizontal resistance of the soil. Morton and Buchele (55) designed a special penetrometer which measured the emergence force of a seedling. Also, Arndt (7, 8) developed a special penetrometer for determining the emergence force of a seedling. Sedgley and Barley (66) described that the data of Morton and Buchele (55) are the most adequate data available on the emergence force of a seedling. They obtained results concerning the energy required for emergence increased directly with depth of planting surface drying, compaction, and indirectly with moisture level at the time of measurement. Wanjura et al. (78) found that there was a negative correlation between penetrometer readings and cotton seedling emergence. They reported that penetrometer recordings gave an appropriate index of soil strength.

Barley and Greacen (9) described three types of failure in soils as created by plant organs. Failure under shearing stresses without compression of the soil, failure under tensity stresses, and failure under shearing stresses with compression of the soil.

Dunlap et al. (27) compared values of soil shear obtained with devices of different geometrical shapes. The following conclusions were taken from his study:

1. The three soil-strength measuring devices--sheargraph, grousered annulus, and NIAE shear box--did not give the same values of the parameters C and ϕ.
2. Relative to C, the sheargraph gave higher values, the NIAE shear box lower values, and the grousered annulus gave values between the two.
3. Accounting for relative displacement did not produce agreement of stresses measured with geometrically different grousered annuli in a single soil and soil condition.
4. The soil's nonuniformity with depth affected the magnitude of measured shearing stress.

Cohron (21, 22) described a portable recording soil sheargraph which was designed to be capable of making rapid measurement of soil shear strength.

Stong and Buchele (71) reported a method of identifying soil strength by means of the "Bekker Soil Values". They discussed the effects of tillage operation, moisture content and bulk density on soil values. Data obtained in these studies shows that plowing has the greatest effect on the soil values while disking has only a small effect. Both tillage operations reduce the soil strength. Panwar and Siemens (58) indicate that the tillage machines are evaluated in terms of the input energy required per unit area or volume of soil manipulated, but terms for evaluating the output have not been well defined. They studied the effects of moisture content and density on the strength parameters and energy to cause failure using soil samples tested under unconfined compression, direct shear, and a model tool. Results were compared with respect to cohesion, angle of internal friction, and energy to cause failure. The following conclusions were drawn form their study. The angle of internal friction:

1. Increased with the bulk density of the soil.
2. Tended to be constant in the upper range of moisture; in the low moisture-content range, it increased as the moisture content was reduced.

The cohesion as well as the angle of the failure plane in the model tool tests were in fair agreement with the values obtained from unconfined and direct shear tests.

Weed Control

James (35) studied the effect of soil aeration on germination of annual weed seeds under field conditions, in the laboratory and in the greenhouse. Different cultivation methods and the injection of CO_2 and O_2 into the soil were employed in four field experiments to modify the soil aeration. Soil aeration, soil temperature and soil moisture were measured and emergence of weed seedlings was determined. The following conclusions were drawn from his study:

1. In three out of the four field experiments, a significant difference was found for cultivation in the emergence of grass seedlings.

2. A significant difference was measured due to treatments for the grass emergence.

Wald (77) compared and evaluated two forms of rotary tillage systems for corn production. The following conclusions were drawn from his study:

1. Weed infestations and plant populations among treatments were slightly depressed under both rotary tillage systems.
2. Corn yields were slightly depressed under both rotary tillage systems.
3. The yields among rotary tillage systems only were similar. The conventional treatment consistently gave the highest yields.

Van Doren (75) conducted an investigation in order to find out if chemicals could be substituted for mechanical weed control and tillage needed for changing soil structure and managing crop residues. The following conclusions were drawn from this study:

1. On plowed soil, disking reduced yield by 6% and cultivation increased yield by 6%.
2. When the soil was not plowed, management systems providing a high percentage of organic residue surface cover or which included cultivation increased yield much more than disking.
3. The top producing nonplowed treatments yielded 13% more corn than plowed treatments.

Erbach et al. (28) conducted preliminary experiments in order to evaluate chemical and mechanical weed control for soybeans grown with no-plow tillage systems. The following results were drawn from their study:

1. It is possible to grow soybeans without preplant tillage to get

good weed control.

2. This weed control was obtained with a preplant treatment of paraquat followed with an incorporated preemergence herbicide treatment.

3. In performing the incorporation and cultivation tillage, it was observed that the rolling cultivator worked quite well under trashy unplowed conditions.

Lovely et al. (49) investigated the effectiveness of the rotary hoe as a shallow cultivating implement for control of annual weeds in soybeans. The following conclusions were drawn from his study:

1. Rotary hoeing performed when weeds were germinating but not emerged, and repeated once or twice at approximately five-day intervals, reduced weed infestations 70 to 80% and soybean stands about 10% in solid-seeded and row-planted soybeans.

2. Wet soil conditions before or after hoeing reduced its effectiveness.

3. Delaying the rotary hoe treatments until weeds had emerged reduced the degree of weed control and bean yields obtained about 50% as compared to the timely use of the hoe.

Plant Population

The subject of corn production and associated plant population has been extensively reviewed by Dungan, Lang, and Pendleton (26) in 1958.

The response of the specific rate of planting to the highest yields per unit area has been shown in detail by Schwanke (65), and Timmons et al. (73). This response depends upon the local conditions under which corn is grown.

Investigators have demonstrated that yield response due to increases in populations varies widely according to different limiting factors (52, 56, 62). Timmons et al. (73) realized their highest yields at 14,000 to 20,000 plants per acre under adequate moisture content and at 6,000 to 12,000 plants per acre under inadequate moisture. Maximum yields were realized by Stickler (70) at 20,000 to 24,000 plants per acre under irrigation. Optimum plant densities were reported by Dungan et al. (26) being 12,000 plants per acre on red-yellow podzolic soils and a range of 8,000 to 24,000 plants per acre on corn belt soils.

Many results have been reported under different conditions with optimum populations ranging between 2,000 plants per acre to higher than 28,000 plants per acre. Carmer and Jackobs (20), in 1965, reported work on a model for predicting the optimum plants densities and maximum yield.

Beer et al. (13) reported on the basis of a six-year irrigation experiment on Colo clay loam near Ames, Iowa. Maximum yields were obtained with a stand of 18,000 to 22,000 plants per acre when fertility was not limiting and when the moisture content of the soil in the rooting zone was maintained at 60% of the available water-holding capacity throughout the entire growing season.

Erbach et al. (29) conducted experiments to investigate the effect of planter-furrow openers on plant spacing and yield and the effect of intra-row plant spacing on individual plant yield and on total yield. The following conclusions were drawn from their study:

1. The planter-furrow openers investigated in this study had little effect on yield or on uniformity intra-row plant spacing.

2. Intra-row plant spacing accounted for only a small amount of the variance in individual corn plant yield.
3. The calculated yield increased with uniform intra-row plant spacing compared with the spacing obtained with conventional planters.

OUTLINE OF THE FIELD OPERATIONS

Equipment needed for the tillage operations for all of the tillage systems were used in this study. To evaluate the tillage system for bio-factors of plants and physical properties of soil, five different cultural systems were selected:

1. Fall plow
2. Plant on ridges
3. Chisel plow
4. Disk
5. No till

The following operations were performed in this study.

Fall Plow

Year	Date	Operation
1971	December	plowed
1972	April 13	applied 445 lb/A of nitrogen as urea
	April 18	applied 2 lb/A Atrazine and $2\frac{1}{2}$ lb/A Alachlor
	May 4	disked and harrowed
	May 4	planted
	June 16	cultivated with sweep cultivator
	June 16	applied 1 lb/A Carbofuran
	October 5	harvested

Plant on Ridges

Year	Date	Operation
1972	April 13	stalks chopped
	April 13	applied 445 lb/A of nitrogen as urea
	April 18	applied 2 lb/A Atrazine and $2\frac{1}{2}$ lb/A Alachlor
	May 4	planted
	June 16	applied 1 lb/A Carbofuran
	June 16	cultivated with ridge cultivator
	October 5	harvested

Chisel Plow

Year	Date	Operation
1972	April 13	stalks chopped
	April 13	applied 445 lb/A of nitrogen as urea
	May 4	chisel plowed and harrowed
	May 4	planted
	May 5	applied 2 lb/A Atrazine and $2\frac{1}{2}$ lb/A Alachlor
	June 16	cultivated with sweep cultivator
	June 16	applied 1 lb/A Carbofuran
	October 5	harvested

Disk

Year	Date	Operation
1972	April 13	stalks chopped

Year	Date	Operation
1972	April 13	applied 445 lb/A of nitrogen as urea
	April 18	applied 2 lb/A Atrazine and $2\frac{1}{2}$ lb/A Alachlor
	May 4	disked
	May 4	planted
	June 16	cultivated with sweep cultivator
	June 16	applied 1 lb/A Carbofuran
	October 5	harvested

No Till

Year	Date	Operation
1972	April 13	stalks chopped
	April 13	applied 445 lb/A of nitrogen as urea
	April 18	applied 2 lb/A Atrazine and $2\frac{1}{2}$ lb/A Alachlor
	May 4	planted
	June 16	cultivated with sweep cultivator
	June 16	applied 1 lb/A Carbofuran
	October 5	harvested

DESCRIPTION OF EQUIPMENT

The sampling equipment used to obtain desired measurements were: a core sampler, penetrometer, sheargraph and a Veihemeir soil sampling tube.

Core Sampler

A motor driven, soil core sampler designed, developed and patented by Buchele (18) at Iowa State University was used to obtain undisturbed soil samples. The device or sampler was used to remove 3-inch diameter by 3-inch long soil cores to a depth of 15 inches. Figure 1 shows a sectional view of column sampler.

Soil Cone Penetrometer

A penetrometer (ASAE Recommendation: ASAE R313) is a device which measures the force required to drive a plunger into the soil. Figure 2 shows the structure of the soil cone penetrometer used in this study. When the cone penetrometer is pushed into the soil at a constant rate resisting the force of the soil is read from a dial.

The resisting force of the soil on the cone penetrometer is an index of the strength of the soil and is called the cone index, in that plane.

The test procedure used for the cone penetrometer is as follows:

1. An operator, who presses the cone penetrometer into the soil, calls out each depth for readings.
2. A recorder, who records the dial readings.
3. Soil surface for testing must be flat, clean and void of any unnecessary disturbance.

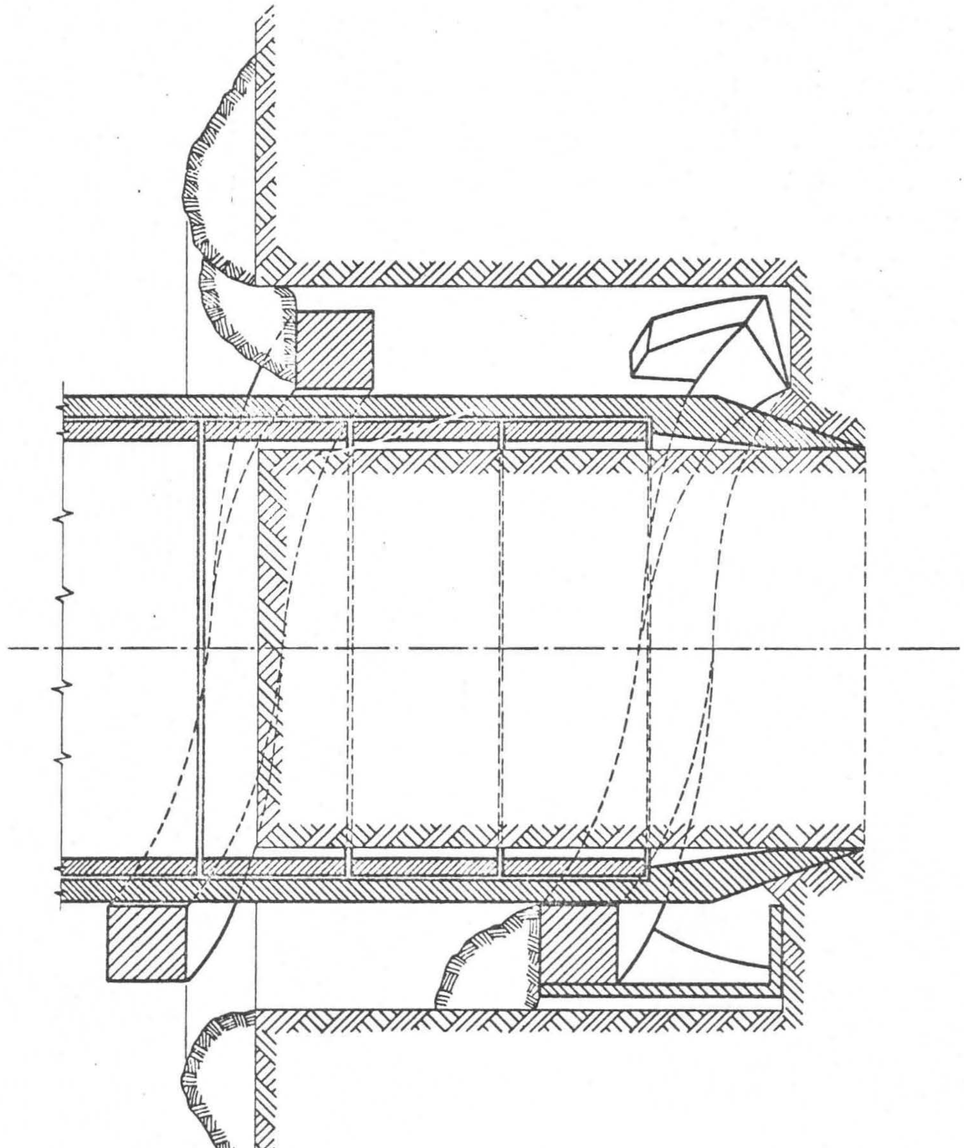

Figure 1. Sectional view of the powered column sampler of undisturbed soil

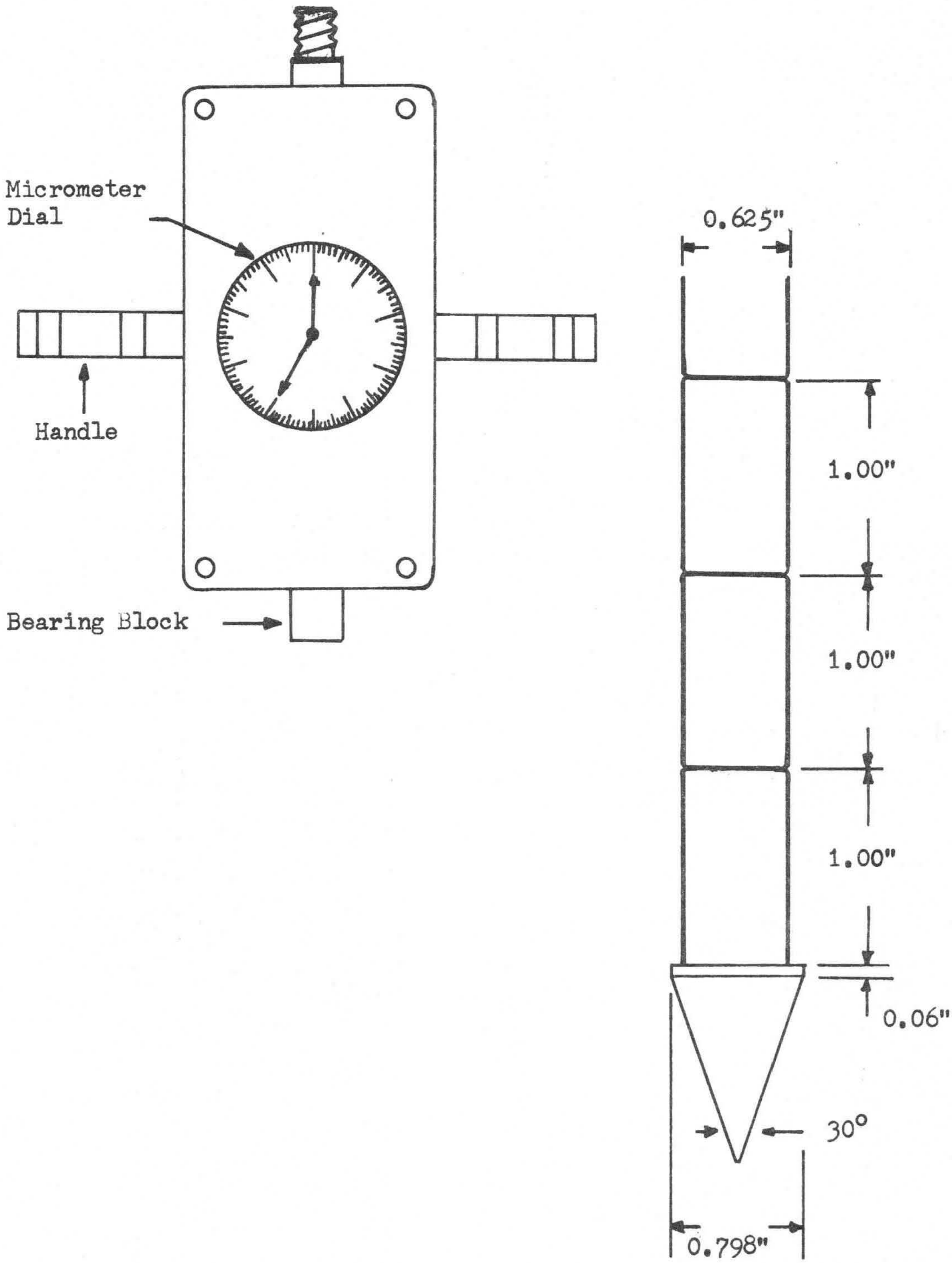

Figure 2. Cone penetrometer

4. The dial is zeroed while the instrument is suspended in a vertical position.
5. The cone is placed on the surface of the soil in such way that the instrument is held in a vertical position.
6. Force is applied at approximately right angles to minimize eccentric loading.
7. Push the cone point slowly downward into the soil at a uniform rate and read the dial at each desired vertical increment of depth.

The recommended rate of penetration when the base of the cone is at ground level for four readings (surface, 6, 12, and 18 inches) should be about 15 seconds per 6 inches in a continuous penetration. Much slower or faster rates of penetration will yield lower or higher readings, respectively, but the discrepancies will not be large. If the downward force on the penetrometer must be discontinued at some depth, the penetration and measurement may be resumed without introducing error (1).

Soil Sheargraph

A brief description of the basic soil shear strength is presented here to provide the background information necessary for an understanding of the parameters to be determined.

A stress is defined as a force per unit of area. A stress applied to a plane surface of a solid may be resolved into two components: one vertical stress (normal) acting on the horizontal plane known as the normal stress, σ (sigma), and one acting on the surface of the plane known as the shear stress, τ (tau).

The shear strength of a soil may be defined as the ability to resist sliding along internal surfaces within a soil mass. The mechanics of soil shear strength are complex and not completely understood. However, an empirical equation, originally proposed by Coulomb in 1776 and widely used in soil analysis and design is:

$$\tau = C + \sigma \tan\phi$$

τ is the shear strength, the maximum static resistance of the soil to sliding along a given surface, and is expressed in terms of stress. C denotes the apparent cohesion and ϕ denotes the angle of internal shearing resistance, both in terms of effective stress, and σ denotes the effective normal stress. The Coulomb equation, $\tau=C+\sigma\tan\phi$, represents a special case of the Mohr theory of strength in which the Mohr envolepe is a straight line inclined to the normal axis at an angle ϕ.

The empirical parameters C and ϕ are not constant properties of a soil, but vary somewhat depending on the test conditions under which they are determined. Moisture content, bulk density, stress conditions, and rate of shearing strain are among the conditions which may affect the observed values of C and ϕ.

Figure 3 shows the structure of the soil sheargraph used in this study. This soil sheargraph was described by Cohron (21, 22). The device was designed to obtain rapid measurement of soil shear strength.

The soil sheargraph consists essentially of a shear head, a spring, a recording pen, a recording drum, bearings, and a handle. The shear head is the base of the sheargraph. The lower end of the spring is connected to the shear head. The upper end of the spring is connected to the recording drum. The lower end of the recording pen is attached to the shear

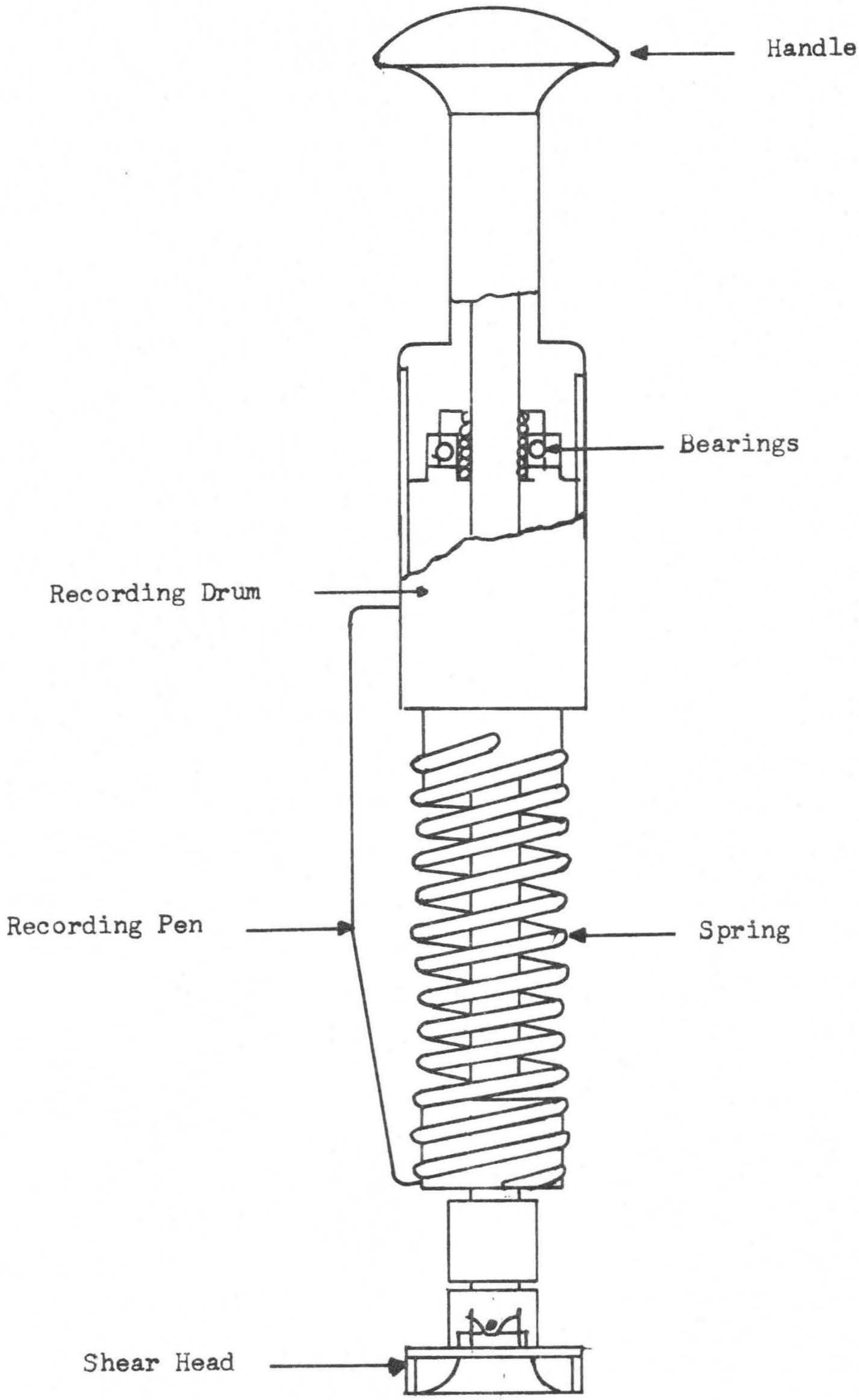

Figure 3. Structure of the soil sheargraph

head. The upper end of the recording pen is in contact with the recording drum. A recording chart is placed between the drum and recording pen which is used to trace a curve of shearing stress versus normal stress. The upper part of the recording drum is attached to a handle.

The test procedure for using the soil sheargraph is as follows:

1. A flat surface selected and prepared by removing loose crop residue.
2. The soil sheargraph is carefully pressed into the soil to the depth of the shear head and a constant vertical load is maintained on the handle by hand pressure.
3. The handle is rotated, winding up a helical spring until the shear head begins to rotate in the soil (Figure 4).
4. After soil failure, the load is gradually released and head continues to rotate, unwinding the spring.
5. The recording pen traces a curve of shearing stress versus normal stress on a recording chart (Figure 5).
6. When cleaning soil from shear head, keep sheargraph inclined so that dust will not fall into guide rod bearings in drum. There is no dust seal, only a close clearance to minimize friction.

Veihemeir Soil Sampling Tube

A 3/4-inch diameter soil sampling tube was used to collect soil samples for the determination of bulk density and soil moisture content after the soil sheargraph test. Several depth marks at 1 inch intervals were made on the tube so that a 6 inch depth could be identified. Both the upper and lower 2 inch columns were discarded. The middle 2 inch columns

Figure 4. Soil sheargraph in use

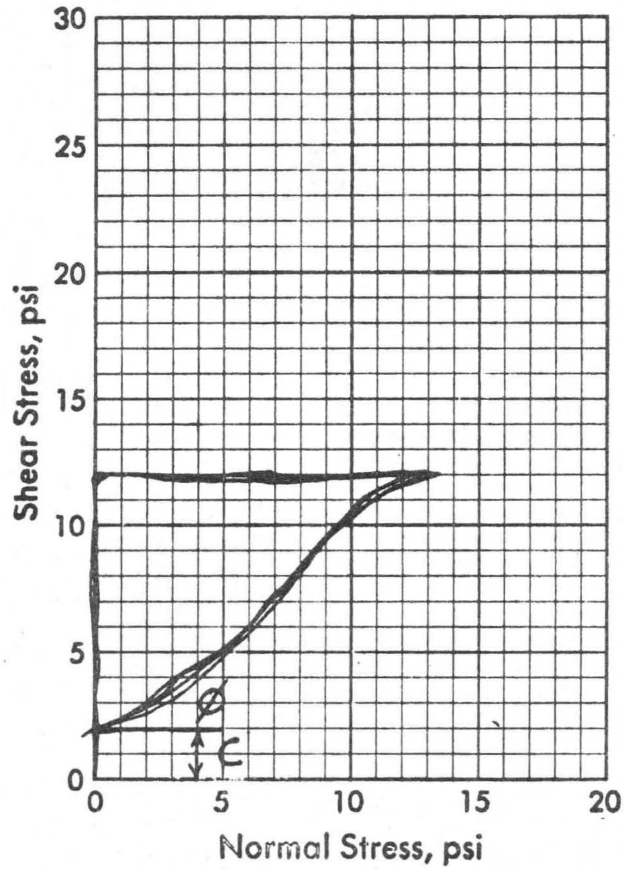

Figure 5. Recording chart showing the position of samples data provided by soil sheargraph

were placed into airtight metal cans for weighing and opened for oven drying. Figures 6 and 7 show soil sample used and the collecting of soil samples respectively.

Figure 6. Soil sampling tube in use after the soil sheargraph test

Figure 7. Collecting of soil samples for determination of soil moisture content and bulk density

EXPERIMENTAL METHODS

Experimental Site and Design

The site for the tillage experiment was on the Agronomy and Agricultural Engineering Research Center located 6 miles west of Ames, Iowa.

The soil on this site is a Clarion-Nicollet-Webster soil association with a flat, uniform-appearing surface. Clarion soils have a surface layer, about 10 to 14 inches thick, and is very dark brown loam. The subsoil is typically brown to yellowish-brown and is a moderately permeable loam. The surface layer of Nicollet soils is a very dark brown to black loam to clay loam which is 15 to 18 inches thick. The subsoil is a moderately permeable loam to clay loam which has a mixed gray and brown color. The surface layer of Webster soils is a black, gritty, silty clay loam 15 to 20 inches thick. The subsoil is a gray to olive gray, moderately permeable, friable to firm loam to clay loam.

A randomized complete block experimental design with five replications and five treatments was used. The following equation characterizes the model for RCBD design:

$$Y_{ij} = u + T_i + B_j + E_{ij}$$

where:

Y_{ij} = observed values of i^{th} treatment in the j^{th} experimental unit

u = general mean

T_i = true effect of the i^{th} treatment

B_j = true effect of the j^{th} treatment

E_{ij} = true effect of the experimental unit in the j^{th} block subjected to the i^{th} treatment

Figure 8 shows a plot layout with dimensions of the general design which was used. Each plot was 20 feet wide and 90 feet long. Five replications of five treatments were used making a total 25 plots.

The five treatments were:

1. Fall plow
2. Plant on ridges
3. Chisel plow
4. Disk
5. No till

The symbols assigned to each of these tillage treatments were FP, PR, CP, D, C, respectively.

Cultural Practices

Continuous corn had been planted in the field plots since 1965. This was the eighth consecutive corn on corn. Fertilizer treatments were applied each year beginning in 1965, including a uniform nitrogen-phosphorus-potassium application of approximately 200-100-100 lbs/acre.

Tillage planting operations were performed on May 4 for all plots. An adapted variety, P3571, was planted in the experiment. Corn was planted at a rate of 30,000 kernels/acre. Chemical insecticides and herbicides were employed and the management practices followed were optimum. All plots were cultivated on June 16. The plots were harvested on October 5.

Physical Measurements

Bulk density and moisture content, both on oven-dry weight basis, were determined on undisturbed soil cores, 3 inches in diameter and 3

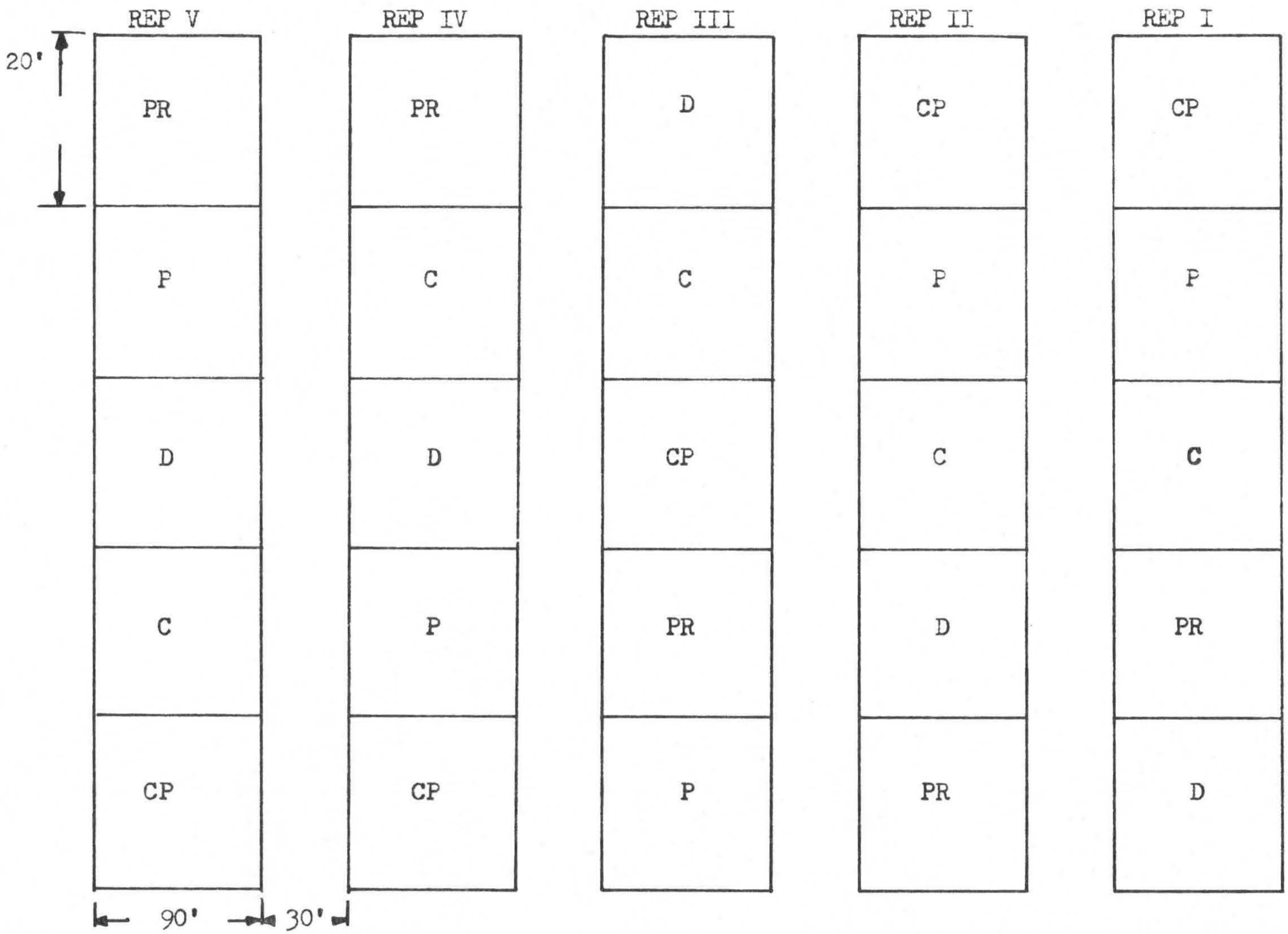

Figure 8. Layout and dimensions of plots used in the experiment

inches long, taken with a power-driven core sampler discussed in the section on equipment. Core samples were taken on each replication to a 15-inch depth and were cut into 3-inch lengths and each length then placed in moisture cans. The samples were then transported to the laboratory where they were weighed before and after oven-drying at 105° C for 48 hours. The bulk density as well as the moisture content could then be calculated.

The bulk density and moisture content determinations were made before and after tillage-planting and before and after cultivation of the plots. Two samples were obtained in the furrow and two in the row for each plot.

Penetrometer readings were taken with a cone penetrometer. The penetrometer was calibrated with a balance. Pressure was applied to the penetrometer on the balance, and penetrometer scale readings were compared to the force indicated by the balance. The penetrometer readings were taken at 1-inch intervals between 0 to 7 inches and one reading each at 14-inch and 21-inch depths. In order to facilitate statistical analysis and to avoid data overlap the maximum observation between 0 to 7 inches depth was taken for tabulation. Penetrometer readings were expressed as force per unit area (psi) which is called "cone index". This is actually pounds of force on the handle divided by area of the cone base in square inches. The cone index readings were taken in the plots just before and as soon as possible after tillage-planting and before and after cultivation operations. Two samples were obtained in the furrow and two in the row for each plot.

The soil sheargraph as discussed in the section on equipment was used for measuring the cohesion and angle of internal friction of soil. The soil sheargraph was calibrated by the use of a balance. Pressure was applied to the soil sheargraph on the balance, and recording chart scale readings were compared to the force indicated by the balance.

Values of angle of internal friction and cohesion of soil were determined on each plot as soon as possible before and after tillage-planting and before and after cultivation operations. Two samples were obtained in the furrow and two in the row for each plot. Each sample consisted essentially of five trials which were graphed on a recording chart.

In order to get information about the conditions which may affect the observed values of cohesion and angle of internal friction, it was necessary to determine the bulk density and moisture content existing within a 3-inch radius around the sheargraph point. A Veihemeir tube as described in the section on equipment was used for determining bulk density and moisture content. Five sub-samples were collected within a 3-inch radius around the sheargraph point and combined to form each sample. The samples were oven-dried for determination of the moisture content and bulk density.

Bio-factor of Plant Measurements

Plant height measurements consisted of measuring the extended leaf height of the tallest plant in 10 hills of each plot. Corn plant height measurements were taken for two dates during the growing season. The plants which were measured were selected at random from the four center rows of each plot.

Stand counts were determined by counting the corn plants in 90 foot row lengths. The plants which were measured were taken from the four center rows of each plot. Corn stand counts were made for six dates during the growing cycle. Each stand count was averaged and used for calculating the plant population for the plot in plants per acre.

Corn yields were harvested at normal harvest time. The corn harvested from each plot was weighed and was sampled for moisture (oven dry) to correct the yield of corn in bushels per acre to 15.5% moisture content.

Weed infestation samplings were made by hand harvesting the weeds from the four center rows of each plot. Two 6-square-feet random weed samples were collected and dried for moisture content determinations. A 6-feet-long and 1-foot-wide frame was used for measuring the area from which all weeds were collected.

The samplings for each plot were averaged, corrected to a dry weight basis and then used to calculate weed weight in pounds of dry matter per acre.

Statistical Analyses

A split plot experimental design or modifications of it with the whole plots arranged in randomized blocks was employed to analyze the data in the experiment. Treatment (tillage systems), position, treatment x position, depth, treatment x depth, position x depth and treatment x position x depth were considered important parameters of the experiment. The Statistical Analysis System (SAS) which has been installed at Iowa State University Computation Center was used for the analyses of variance. The model assumed for the individual analysis of each parameter was as follows:

$$Yijklm = \upsilon + (REP)_i + (TRT)_j + (REPxTRT)_{ij} + (POS)_K + (TRTxPOS)_{jk} + (REPxPOS)_{ik} + (REPxTRTxPOS)_{ijk} + (DEP)_l + (TRTxDEP)_{jl} + (POS+DEP)_{kl} + (TRTxPOSxDEP)_{jkl} + (REPxDEP)_{il} + (REPxTRTxDEP)_{ijl} + (REPxTRTxDEP)_{ijl} + (REPxPOSxDEP)_{ikl} + (REPxTRTxPOSxDEP)_{ijkl} + \delta ijklm$$

Where:

υ = mean

$(REP)_i$ = i^{th} replication; i = 1 to 5

$(TRT)_j$ = j^{th} treatment; j = 1 to 5

$(REPxTRT)_{ij}$ = error (a)

$(POS)_k$ = k^{th} position; k = 1 to 2

(DEP) = th depth; = 1 to 5

$(REPxPOS)_{ik} + (REPxTRTxPOS)_{ijk}$ = error (b)

$(REPxDEP)_{il} + (REPxTRTxDEP)_{ijl} + (REPxPOSxDEP)_{ikl} + (REPxTRTxPOSxDEP)_{ijkl}$ = error (c)

$\delta ijklm$ = sampling error with split plot

Combination of symbols refer to interactions between main effects. A set of four orthogonal comparisons for treatment mean was prepared to investigate the treatment effects. The orthogonal comparisons considered in the model for the analysis of variance were as follows:

C_1 = orthogonal comparison of the conventional system versus disk, plant on ridges, chisel plow and no tillage.

C_2 = orthogonal comparison of no tillage versus chisel plow, plant on ridges and disk.

C_3 = orthogonal comparison of plant on ridges versus chisel plow and disk.

C_4 = orthogonal comparison of chisel plow versus disk.

A correlation matrix was calculated for stand count, weed weight, and yield observations. In addition, three types of analyses were fitted to the corn yields: a regression analysis for replications, and weed weight, final stand count, height of plants determinations as covariates, and the principal components analysis for cone index. The analysis of variance calculated for corn yield data was as follows:

$$Yij = \upsilon + (TRT)_i + (REP)_j + \phi_1(Xij^{(1)} - \bar{x}^{(1)}) + \phi_2(Xij^{(2)} - \bar{x}^{(2)}) + \phi_3(Xij^{(3)} - \bar{x}^{(3)}) + \phi_4(Xij^{(4)} - \bar{x}^{(4)}) + \phi_5(Xij^{(5)} - \bar{x}^{(5)}) + \phi_6(Xij^{(6)} - \bar{x}^{(6)}) + Eij$$

Where:

υ	= mean
$(TRT)_i$	= i^{th} treatment; i = 1 to 5
$(REP)_j$	= j^{th} replication; j = 1 to 5
$\phi_1(Xij^{(1)} - \bar{x}^{(2)})$	= adjusting treatment means of final stand count
$\phi_2(Xij^{(2)} - \bar{x}^{(2)})$	= adjusting treatment means of weed weight
$\phi_3(Xij^{(3)} - \bar{x}^{(3)})$	= adjusting treatment means of height of plants
$\phi_4(Xij^{(4)} - \bar{x}^{(4)})$	= adjusting treatment means of contrast 1 cone index
$\phi_5(Xij^{(5)} - \bar{x}^{(5)})$	= adjusting treatment means of contrast 2 cone index
$\phi_6(Xij^{(6)} - \bar{x}^{(6)})$	= adjusting treatment means of contrast 3 cone index
Eij	= error

RESULTS AND DISCUSSION

Tillage-Planting Operations and Physical Measurements

Moisture content

The mean values of soil moisture content before tillage-planting operations are presented in Table 1. The moisture content shown in this table is indicative of the moisture content of the different tillage systems before tillage and planting operations were performed. The table shows the range to be from a low of about 20% mean soil moisture content in furrow for plant on ridges treatment to a high of about 23% mean soil moisture content in furrow for chisel plow treatment. Likewise, the mean soil moisture content in row shows a range from 22.71% in plant on ridges treatment to 24.99% in no till treatment. The no till treatment sampled showed the highest range of differences (9.85%) in row, with about 4.82% from 0 to 6 inches depth. The lowest range of differences (1.71%) was found in plant on ridges in row position, with about 1.47% from 0 to 6 inches depth. The overall means for furrow and row position were 21.70 and 24.12% respectively.

An analysis of variance for moisture content before tillage-planting operations is shown in Table A-1, Appendix A. The analysis of variance showed significant differences between furrow and row position, as explained by the relative difference of the two overall means. The main effect of depth was highly significant, as a result of the large depth-to-depth fluctuations given in Table 1.

Table 1. Soil moisture content before tillage-planting operations

Tillage system	Depth (inches)	Percent moisture content	
		Furrow	Row
Fall plow	0 - 3	24.76	24.41
"	3 - 6	21.61	25.91
"	6 - 9	20.98	25.82
"	9 - 12	21.71	23.58
"	12 - 15	19.81	22.40
	Mean	21.77	24.42
Plant on ridges	0 - 3	19.68	22.30
"	3 - 6	19.23	23.77
"	6 - 9	19.96	24.01
"	9 - 12	21.21	22.83
"	12 - 15	20.23	20.62
	Mean	20.06	22.71
Chisel plow	0 - 3	24.42	25.69
"	3 - 6	23.36	27.05
"	6 - 9	23.16	23.70
"	9 - 12	23.29	23.99

Table 1. Continued

Tillage system	Depth (inches)	Percent moisture content	
		Furrow	Row
Chisel plow	12 - 15	21.50	21.79
	Mean	23.14	24.44
Disk	0 - 3	21.68	25.16
"	3 - 6	19.85	27.13
"	6 - 9	21.59	24.98
"	9 - 12	21.91	22.31
"	12 - 15	20.69	20.72
	Mean	21.14	24.06
No till	0 - 3	23.78	30.42
"	3 - 6	22.73	25.61
"	6 - 9	23.38	24.33
"	9 - 12	22.07	23.51
"	12 - 15	19.97	21.07
	Mean	22.39	24.99
Overall mean		21.70	24.12

The mean performance of tillage system plots for soil moisture content after tillage-planting operations is presented in Table 2. The table indicates that the variability between samples was low in 0 to 6 inches depth. Likewise, the variability between positions (furrow and row) was low in 0 to 6 inches depth. Ranges of over 2% in the soil moisture content were found at most depths, with about 4% from 0 to 3 inches. The mean soil moisture content varied only slightly between any of the tillage systems studied in the experiment. Table 2 shows the range to be from a low of 23.18% mean soil moisture content in furrow for fall plow treatment to a high of 25.15% in furrow for chisel plow treatment. A range from 23.02% in chisel plow treatment to 24.89% in plant on ridges, was found for mean soil moisture in row position. The range of differences in the percent of moisture content of all of the tillage systems was 1.97% in furrow and 1.87% in row position. As can be noted in Table 2, the moisture content of the furrow position was slightly larger than the moisture content of the row position.

An analysis of variance for moisture content after tillage-planting operations is presented in Table A-2, Appendix A. The table indicates a highly significant difference among depths at the 1% level, as shown by variation of the soil moisture content between individual depths. The difference between treatments was not significant. This would be expected since the soil moisture content did not give large difference among tillage systems.

The data of the soil moisture content for change (after - before) tillage-planting operations are given in Table 3. The negative values for

Table 2. Soil moisture content after tillage-planting operations

Tillage system	Depth (inches)	Percent moisture content	
		Furrow	Row
Fall plow	0 - 3	24.24	24.63
"	3 - 6	25.59	27.08
"	6 - 9	26.36	24.42
"	9 - 12	20.63	20.94
"	12 - 15	19.05	19.27
	Mean	23.18	23.27
Plant on ridges	0 - 3	28.29	26.51
"	3 - 6	27.46	26.84
"	6 - 9	26.26	26.51
"	9 - 12	23.79	22.93
"	12 - 15	19.93	21.68
	Mean	25.15	24.89
Chisel plow	0 - 3	27.05	25.30
"	3 - 6	25.76	24.60
"	6 - 9	24.53	23.20
"	9 - 12	21.70	21.76

Table 2. Continued

Tillage system	Depth (inches)	Percent moisture content	
		Furrow	Row
Chisel plow	12 - 15	19.79	20.26
	Mean	23.77	23.02
Disk	0 - 3	26.73	26.63
"	3 - 6	26.32	26.31
"	6 - 9	24.27	22.45
"	9 - 12	22.25	21.18
"	12 - 15	19.27	19.87
	Mean	23.77	23.29
No till	0 - 3	26.19	26.16
"	3 - 6	25.17	25.77
"	6 - 9	25.46	24.31
"	9 - 12	24.72	23.87
"	12 - 15	19.68	20.74
	Mean	24.24	24.17
Overall mean		24.02	23.73

Table 3. Soil moisture content change (after - before) tillage-planting operations

Tillage system	Depth (inches)	Percent moisture content	
		Furrow	Row
Fall plow	0 - 3	-0.52	0.22
"	3 - 6	3.97	1.17
"	6 - 9	5.38	-1.40
"	9 - 12	-1.07	-2.64
"	12 - 15	-0.75	-3.13
	Mean	1.40	-1.15
Plant on ridges	0 - 3	8.61	4.21
"	3 - 6	8.23	3.06
"	6 - 9	6.29	2.49
"	9 - 12	2.58	0.09
"	12 - 15	-0.30	1.06
	Mean	5.08	2.18
Chisel plow	0 - 3	2.63	-0.39
"	3 - 6	2.39	-2.45
"	6 - 9	1.37	-0.50
"	9 - 12	-1.58	-2.23

Table 3. Continued

Tillage system	Depth (inches)	Percent moisture content Furrow	Row
Chisel plow	12 - 15	-1.70	-1.53
	Mean	0.62	-1.42
Disk	0 - 3	5.04	1.46
"	3 - 6	6.47	-0.82
"	6 - 9	2.68	-2.53
"	9 - 12	0.33	-1.13
"	12 - 15	-1.41	-0.85
	Mean	2.62	-0.77
No till	0 - 3	2.41	-4.25
"	3 - 6	2.43	0.15
"	6 - 9	2.08	-0.02
"	9 - 12	2.64	0.35
"	12 - 15	-0.29	-0.33
	Mean	1.85	-0.81
Overall mean		2.31	-0.39

percent of soil moisture content change (after - before) mean that the soil moisture content before tillage was higher than after tillage-planting. A positive value indicates that the soil moisture content after tillage was higher than before tillage-planting.

Data in Table 3 show that the range is from a low of 0.62% mean soil moisture content in furrow for chisel plow treatment to a high of 5.08% in furrow for plant on ridges treatment. Likewise, the mean soil moisture content change in row position showed a range from 1.42% in chisel plow treatment to 2.18% in plant on ridges treatment. Highest and lowest ranges of difference for furrow position were found in plant on ridges (8.91%) and no till treatment (2.93%). Highest and lowest range of difference for row position were found in no till treatment (4.60%) and chisel plow treatment (-2.06%) respectively. The soil moisture content change ranges from 4.49 to -2.06 in the replicated plots for the depth 0 to 6 inches. The plow plot is distinctly different with 4.49% for 0 to 6 inches in furrow position and 0.95% for 0 to 6 inches in row position. The chisel plow plot had a range of -2.06% for the depth 0 to 6 inches in row position while the furrow position had a range of 0.24% for the same depth. The disk plot showed a range of 1.43% for the depth 0 to 6 inches in furrow position and 2.28% in row position. The plant on ridges plot had 0.38 and 1.15% for the same depth in furrow and row position respectively. No till plot showed 0.02 and 4.40% for 0 to 6 inches depth in furrow and row position respectively. The overall means for furrow and row position were 2.31 and -0.39 respectively.

The data for soil moisture content change are shown graphically in Figures 9 and 10. The moisture content change for furrow illustrated in Figure 9 indicates that the soil drying rates apparent for fall plow, and do not seem to exist in plant on ridges, disk and no till treatments. The fall plow treatment exhibits a very small drying rate at 0 to 3, 9 to 12 and 12 to 15 inches depth. The chisel plow treatment shows a small soil drying rate at 9 to 12 and 12 to 15 inches depth. Figure 10 illustrates moisture content change as affected by tillage-planting operations in row position. This figure shows that some similarity in soil drying rates seemed to exist in fall plow, chisel plow and disk treatments. These figures indicate that the variation of soil moisture found between the treatments was not necessarily created by the tillage systems on any of the plots for which soil moisture content of soil were obtained.

The analysis of variance for soil moisture content change (after - before) are given in Table A-3, Appendix A. The statistical analysis shows that the tillage system effects are not significant, as can be noted in Table 3, the moisture content of plant on ridges and disk treatments were slightly larger than the moisture content of fall plow, chisel plow and no till treatments. The position was significantly different in furrow and ridge. This would be expected from examination of the overall means. The depth was highly significant, as may be observed in Table 3, the moisture content of the soil decreases with the depth of sampling. Linear effect of depth tested significant (Table A-4, Appendix A). This indicated that the moisture content of the soil decreased linearly with increase in depth.

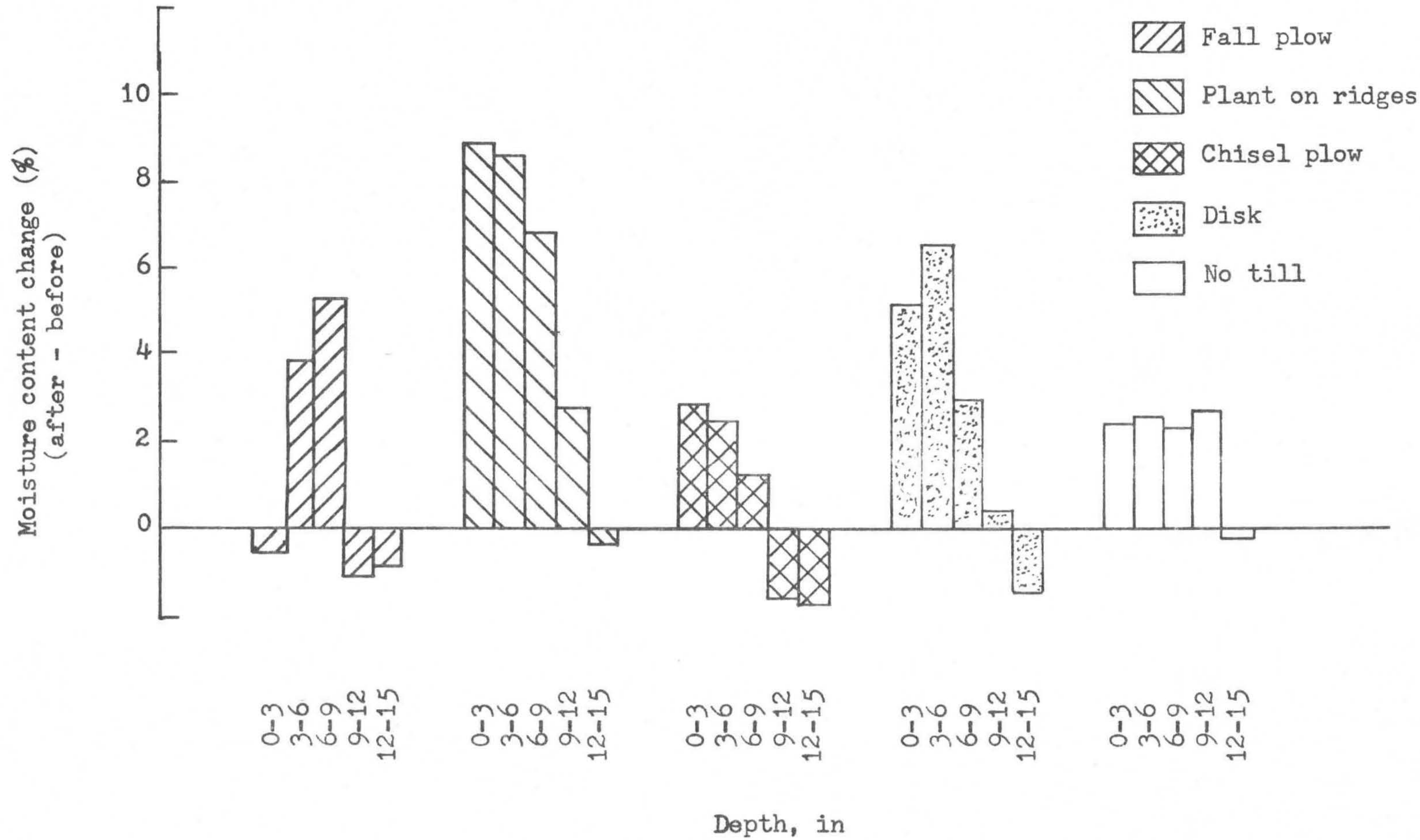

Figure 9. Moisture content changes as affected by tillage-planting operations (furrow)

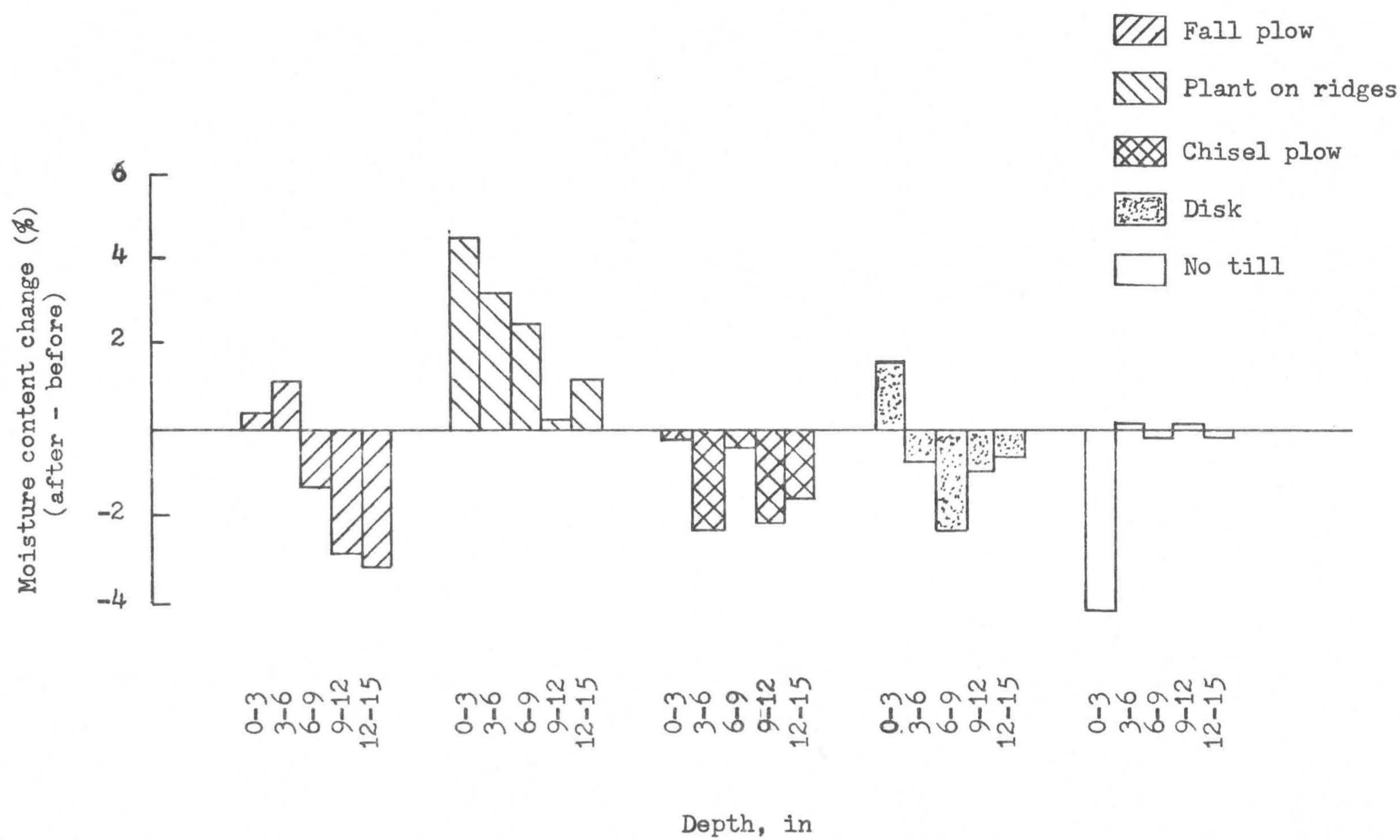

Figure 10. Moisture content changes as affected by tillage-planting operations (row)

It may be concluded that the tillage and planting operations did not materially influence the moisture content of the soil.

Cone index

The data for cone index before tillage-planting are shown in Table 4. The table indicates the cone indexes for the three different depths of 0 to 7, 14 and 21 inches along with the furrow and row position. While the cone index in furrow ranges from 76.83 to 135.05 in the replicated plots for the depth 0 to 7 inches, it is 16.21 for the 14 inches and 15.01 for the 21 inches depth. The fall plow treatment is distinctly different with 76.83 for 0 to 7 inches depth and the range of difference in cone index is 55.22. The range is 10.40 for plant on ridges, 6.20 for chisel plow, 23.21 for disk and 13.61 for no till treatment. The range of difference of all of the tillage systems is 60.82 in furrow position. The highest mean value of cone index in furrow position was reached in chisel plow treatment (133.98). The lowest mean value was found in fall plow treatment (106.37). The data for cone index before tillage-planting operations in row position (Table 4) indicate that the fall plow treatment is different from other treatments with 81.83 for 0 to 7 inches depth and its range of difference is 52.02. The range of difference is 3.21 for plant on ridges, 30.61 for chisel plow, 10.61 for disk and 30.61 for no till treatment. The range of difference of all of the tillage systems for the depth 0 to 7 inches was 42.41; 17.21 for the 14 inches; and 20.60 for the 21 inches depth. The highest mean value of cone index in row position was obtained in chisel plow treatment (131.78). The lowest mean value was

Table 4. Mean cone index before tillage-planting operations

Tillage system	Depth (inches)	Cone index (psi)	
		Furrow	Row
Fall plow	0 - 7	76.83	81.83
"	14	114.24	112.64
"	21	128.05	133.85
	Mean	106.37	109.44
Plant on ridges	0 - 7	135.05	124.24
"	14	126.05	127.05
"	21	136.45	127.45
	Mean	132.51	126.25
Chisel plow	0 - 7	134.85	117.44
"	14	130.45	129.85
"	21	136.65	148.05
	Mean	133.98	131.78
Disk	0 - 7	128.45	123.64
"	14	117.64	129.65

Table 4. Continued

Tillage system	Depth (inches)	Cone index (psi)	
		Furrow	Row
Disk	21	130.85	134.25
	Mean	125.65	129.18
No till	0 - 7	129.45	107.44
"	14	115.89	120.04
"	21	121.64	138.05
	Mean	122.31	121.84
Overall mean		124.16	123.70

reached in fall plow treatment (106.44). The overall means of cone index for furrow and row position were 124.16 and 123.70 respectively.

The analysis of variance for cone index before tillage-planting is shown in Table A-5, Appendix A. The table indicated that the tillage systems had a significant effect on cone index. This can be explained from the values of range of difference of each tillage system.

The data for cone index after tillage-planting are shown in Table 5. The table indicates the cone index for the three different depths of 0 to 7, 14 and 21 inches along with the furrow and row position. While the cone index in furrow ranges from 89.35 to 108.44 in the replicated plots for the depth 0 to 7 inches, the range is 4.20 for the 14 inches and 8.00 for the 21 inches depth. The fall plow treatment is notably different with 89.35 (furrow) for 0 to 7 inches depth and with a range of difference of 29.89. The range is 4.40 for plant on ridges, 8.40 for chisel plow, 9.44 for disk and 16.81 for no till treatment. The range of all the tillage systems is 39.90 in furrow position. The highest mean value of cone index in furrow position was found in no till treatment (114.97). The lowest mean value was reached in fall plow treatment (105.70). The data for cone index after tillage-planting operations in row position (Table 5) indicate that the fall plow treatment is different from other treatments with 93.63 for 0 to 7 inches depth and with a range of difference of 15.21. The range is 33.22 for plant on ridges, 20.41 for chisel plow, 11.60 for disk and 24.21 for no till treatment. The range of difference of all of the tillage systems for the depth 0 to 7 inches was 13.21; it was 16.00 for the 14 inches and 20.81 for the 21 inches depth. The highest mean value of cone index in row position was reached in chisel plow treatment

Table 5. Mean cone index after tillage-planting operations

Tillage system	Depth (inches)	Cone index (psi)	
		Furrow	Row
Fall plow	0 - 7	89.35	93.63
"	14	108.04	104.84
"	21	119.24	108.84
	Mean	105.70	102.44
Plant on ridges	0 - 7	114.04	96.43
"	14	109.64	107.44
"	21	111.24	129.65
	Mean	111.64	111.17
Chisel plow	0 - 7	109.24	104.64
"	14	109.84	115.24
"	21	117.64	125.05
	Mean	112.24	114.97
Disk	0 - 7	110.44	106.84
"	14	107.04	118.04

Table 5. Continued

Tillage system	Depth (inches)	Cone index (psi)	
		Furrow	Row
Disk	21	116.84	118.44
	Mean	111.44	114.44
No till	0 - 7	108.44	95.43
"	14	111.24	102.04
"	21	125.25	119.64
	Mean	114.97	105.70
Overall mean		111.20	109.75

(114.97). The lowest mean value mean was obtained in fall plow treatment (102.44). The overall means of cone index for furrow and row position were 111.20 and 109.75 respectively.

The analysis of variance for cone index after tillage-planting is shown in Table A-6, Appendix A. The table indicates that the tillage systems did not have a significant effect on cone index. This would be expected from the small differences among tillage system means (Table 5). The difference between depths was found to be highly significant, as would be expected from examination of the average cone index for 0 to 7 inches (102.90), 14 inches (109.34) and 21 inches (119.18). Linear effect of the depth tested highly significant (Table A-7, Appendix A). This means that the cone index of soil increased linearly with increase in depth.

The data of the cone index of the soil for changes (after - before) tillage-planting operations are given in Table 6. The negative values for the cone index change (after - before) mean that the cone index of the soil before tillage was higher than after tillage-planting. A positive value indicates that the cone index of the soil after tillage was higher than before tillage-planting.

In Table 6 the cone index changes (after - before) as affected, by tillage-planting operations in furrow and row position are shown for all of the tillage systems. The same data for cone index in furrow and row positions are presented graphically in Figures 11 and 12. Table 6 indicates the fall plow treatment is distinctly different from the other treatments with 13.00 for 0 to 7 inches depth in furrow position and 11.80 in row position. These inconsistent results suggest that the soil moisture content was low for 0 to 7 inches depth and indicate that the increase in

Table 6. Mean cone index change (after - before) tillage-planting operations

Tillage system	Depth (inches)	Cone index (psi)	
		Furrow	Row
Fall plow	0 - 7	13.00	11.80
"	14	- 6.20	- 7.80
"	21	- 8.80	-25.01
	Mean	- 0.66	- 7.00
Plant on ridges	0 - 7	-21.00	-27.81
"	14	-16.40	-19.60
"	21	-25.21	2.20
	Mean	-20.87	-15.07
Chisel plow	0 - 7	-25.61	-12.80
"	14	-20.60	-14.60
"	21	19.00	-23.00
	Mean	-21.74	-16.80
Disk	0 - 7	-18.00	-16.80
"	14	-10.60	-11.60

Table 6. Continued

Tillage system	Depth (inches)	Cone index (psi)	
		Furrow	Row
Disk	21	-14.00	-15.80
	Mean	-14.20	-14.73
No till	0 - 7	-21.00	-12.00
"	14	- 4.60	-18.00
"	21	3.60	-18.40
	Mean	- 7.33	-16.13
Overall mean		-12.96	-13.95

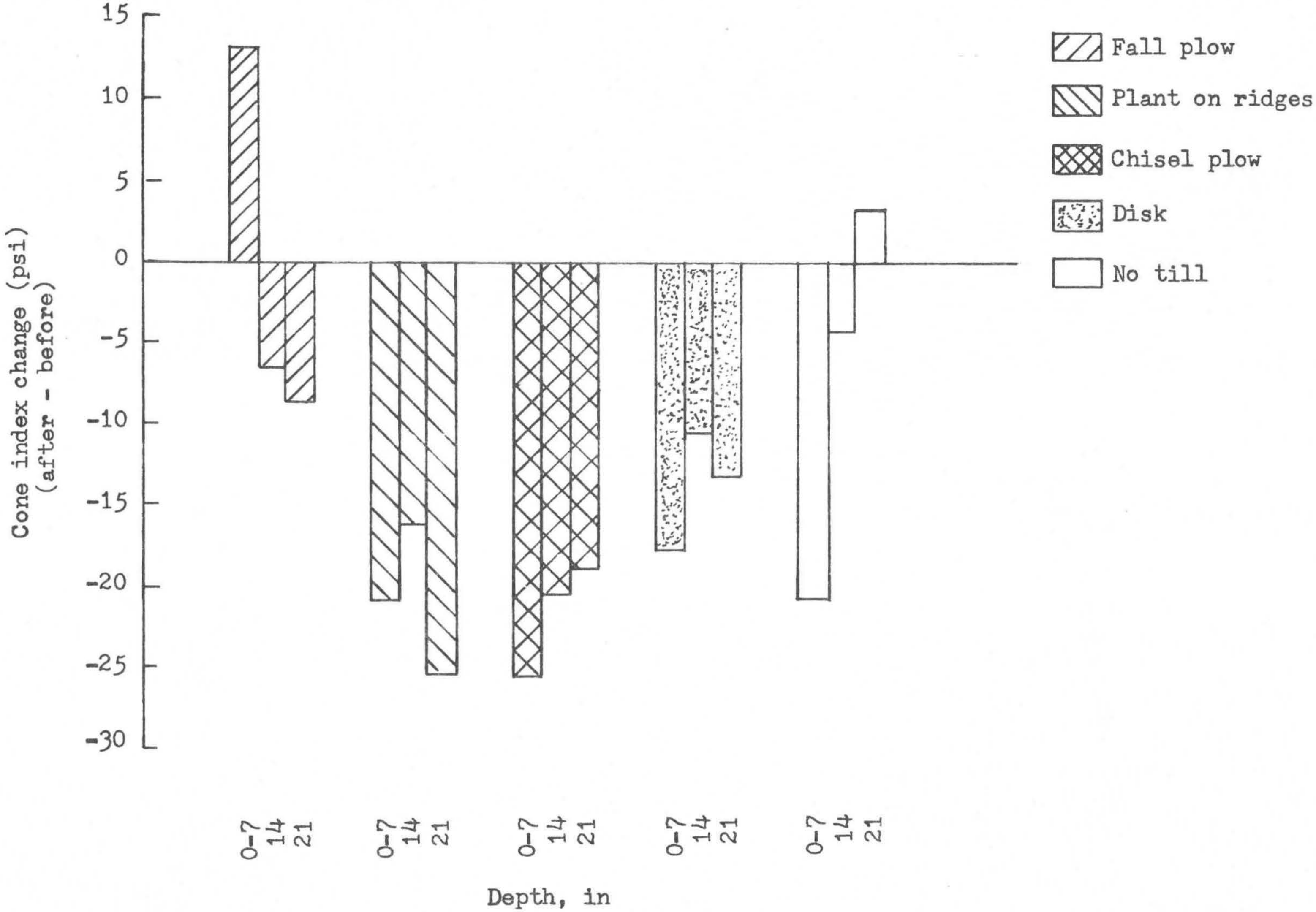

Figure 11. Cone index changes as affected by tillage-planting operations in the furrow

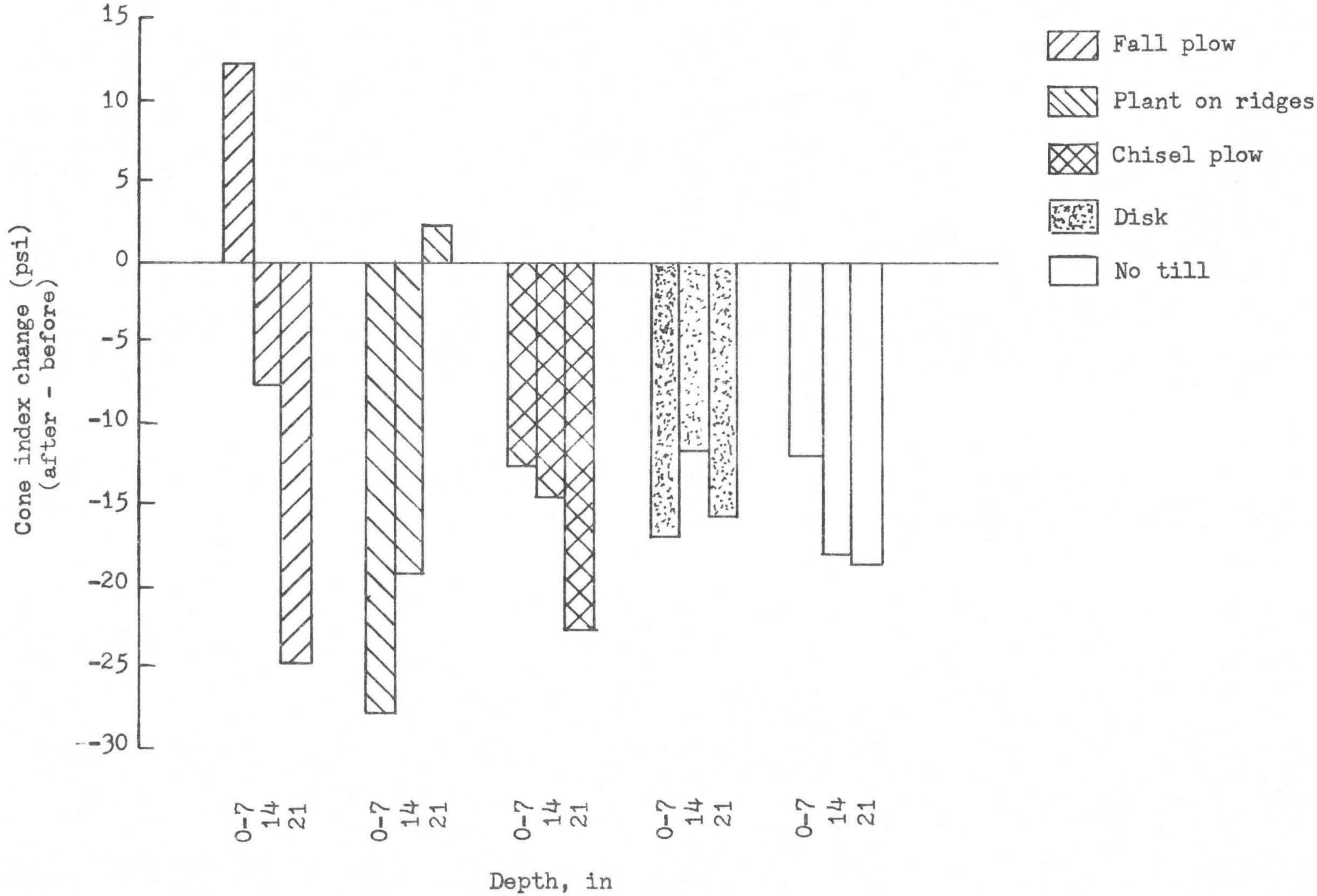

Figure 12. Cone index changes as affected by tillage-planting operations in the row

cone index with decreased moisture content may be attributed to the increase in strength and vicosity of the soil. Plant on ridges and no till treatments show a decrease for cone index in furrow position. These contradictory results indicate that the decrease found in furrow position was not necessarily due to the tillage systems. It may be a result of uncontrolled factors such as moisture content, drying time or random.

The mean cone index resulting from disk treatment for furrow and row position were approximately the same. In fall plow treatment, the row had a larger cone index change than the furrow position. In plant on ridges and chisel plow treatments the cone index was less in the row than that found for furrow position. The cone index change of the soil on chisel plow treatment was larger than any of the mean cone indexes found for the other treatments. In fall plow treatment, the mean cone index change was less than that found for any of the other treatments. The mean cone index changes of all of the tillage systems for the depth 0 to 7 inches was -13.02, it was -13.00 for the 14 inches and -14.34 for the 21 inches depth. The overall means of the cone index change for furrow and row position were -12.96 and -13.95 respectively.

The analysis of variance for cone index change (after - before) tillage-planting operations is shown in Table A-8, Appendix A. Statistical analysis of the data shows that the tillage systems were not significant. Nonsignificance indicates that the tillage systems did not affect the cone index of the soil; however, the overall mean cone index changes of plant on ridges, chisel plow, disk and no till treatments were larger than the overall mean cone index change of fall plow. An orthogonal comparison test on the data from this experiment showed that the conventional system (fall plow) versus all other tillage systems was significant, as would be expected from the small cone index change in fall plow as compared to all others.

The data show some general indications although statistical significance was not shown in tillage systems. Fall plow treatment caused the smallest mean cone index change in all of the tillage systems. Chisel plow treatment created the largest mean cone index change in all of the tillage systems.

It may be concluded that the tillage systems applied in this study have an influence in reducing the cone index of the soil. The effects were shown, although statistical significance was not found in the tillage systems used in this experiment. The fall plow treatment versus all other tillage systems was significant.

Cohesion and angle of internal friction

The data for cohesion and angle of internal friction before tillage-planting operations are shown in Table 7. The table indicates highest cohesion for chisel plow plot in furrow position. Likewise, the table indicates highest angle of internal friction for chisel plow plot in row position. The range of difference of cohesion for all of the tillage systems for furrow and row position was approximately 0.09 and 0.10 psi respectively. The overall means of cohesion for furrow and row position were 1.00 and 0.94 psi respectively.

An analysis of variance for cohesion before tillage-planting operations is given in Table A-9, Appendix A. This table indicates that the tillage systems were not significant, as observed from the small variation

Table 7. Mean values of cohesion (C) and angle of internal friction (ϕ) before tillage-planting operations

Tillage system	C (psi)		ϕ (degrees)	
	Furrow	Row	Furrow	Row
Fall plow	0.80	0.98	37.46	49.12
Plant on ridges	1.01	0.92	39.56	52.63
Chisel plow	1.17	0.88	34.19	54.64
Disk	1.08	0.95	34.85	51.72
No till	0.92	0.97	40.60	52.14
Overall mean	1.00	0.94	37.33	52.05

of the mean values of cohesion among tillage systems (Table 7). The position was not significant, as explained by the slightly smaller difference of the overall means for furrow and row position. Table A-10, Appendix A, shows an analysis of variance for angle of internal friction before tillage-planting operations. The tillage systems had no effect on the angle of internal friction of soil. It may be explained from the difference in angle of internal friction noted in Table 7 are of small magnitudes. The position was found to be highly significant, as expected from examination of overall mean values for furrow (37.33°) and row (52.05°).

The mean values of cohesion and angle of internal friction after tillage-planting operations is shown in Table 8. The table indicates that the chisel plow plot has the lowest value of cohesion in furrow and row position. The disk plot has the highest value of cohesion in furrow position. The fall plow and no till plots have the highest and the same values of cohesion in row position. The mean values of cohesion in furrow shows a range from 0.60 psi in chisel plow treatment to 1.32 psi in disk treatment. The range of the mean values of cohesion of all of the tillage systems was approximately 0.72 psi in furrow and 0.32 psi in row position. Table 8 shows highest angle of internal friction for chisel plow plot in row position and lowest for plant on ridges plot in row position. The range of angle of internal friction of all of the tillage systems for furrow position was 5.08 and 8.85 degrees for row position. The overall means of angle of internal friction for furrow and row position were 53.02 and 52.88 respectively.

An analysis of variance for cohesion and angle of internal friction

Table 8. Mean values of cohesion (C) and angle of internal friction (ϕ) after tillage-planting operations

Tillage system	C (psi)		ϕ (degrees)	
	Furrow	Row	Furrow	Row
Fall plow	0.82	1.12	54.29	53.18
Plant on ridges	1.00	0.82	50.11	48.45
Chisel plow	0.60	0.80	53.48	56.90
Disk	1.32	0.92	52.02	52.02
No till	0.62	1.12	55.19	53.87
Overall mean	0.87	0.96	53.02	52.88

after tillage-planting operations is shown in Table A-11, Appendix A. As can be observed in Table 8, cohesion of the disk treatment was larger than chisel plow, fall plow and no till treatments; however, an analysis of variance of the data shows that the mean square for the five treatments is 0.191 while the mean square for error is 0.160, therefore there is no statistical difference in the values of cohesion between tillage systems. The variation in the angle of internal friction between tillage systems was small therefore there is no statistical difference in the angle of internal friction between tillage systems. (Table A-12, Appendix A).

In Table 9 the mean cohesion, angle of internal friction, moisture content and bulk density change as affected by the tillage-planting operations in furrow are shown for all of the tillage systems. The same data for cohesion and angle of internal friction are shown graphically in Figures 13 and 14. The cohesion change from the chisel plow, plant on ridges and no till treatments decreased. It is indicated for the negative values in Table 9. The fall plow and disk treatments did not decrease. It is indicated for the positive values in Table 9. The reduction of cohesion from the chisel plow were larger than those from plant on ridges and no till treatments. The moisture content and cohesion of chisel plow changed in the same way (-0.575) and bulk density change was found to be -0.412 gms/cc. The same data in Table 9 also show that when the tillage-planting operations were performed in fall plow and disk plots, the cohesion was increased. The amount of such increases were of a very small magnitude for fall plow treatment and small for disk treatment.

From these data it can be concluded that although tillage systems help decrease cohesion, the difference between fall plow and disk

Table 9. Mean changes in cohesion, angle of internal friction, moisture content and bulk density as affected by tillage-planting operations in furrow (after - before)

Tillage system	Furrow[a]			
	C (psi)	ϕ (degrees)	MC (%)	BD (gms/cc)
Fall plow	0.025	17.22	-2.290	-0.604
Plant on ridges	-0.017	10.54	-0.550	-0.547
Chisel plow	-0.575	19.29	-0.575	-0.412
Disk	0.245	17.17	0.165	-0.450
No till	-0.302	14.59	-2.900	-0.313

[a] C = cohesion, ϕ = angle of internal friction, MC = moisture content, BD = bulk density.

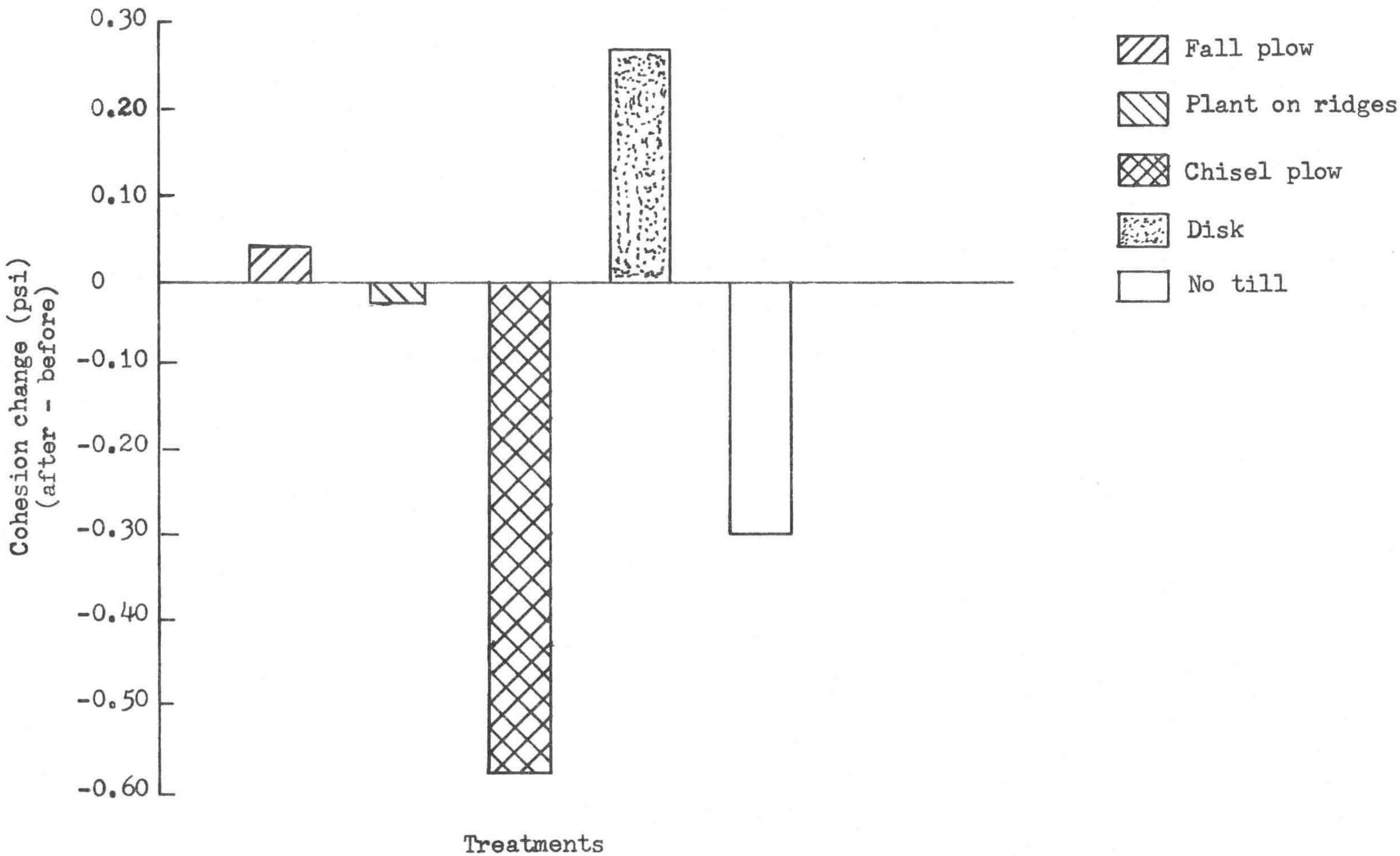

Figure 13. Cohesion changes as affected by tillage-planting operations (furrow)

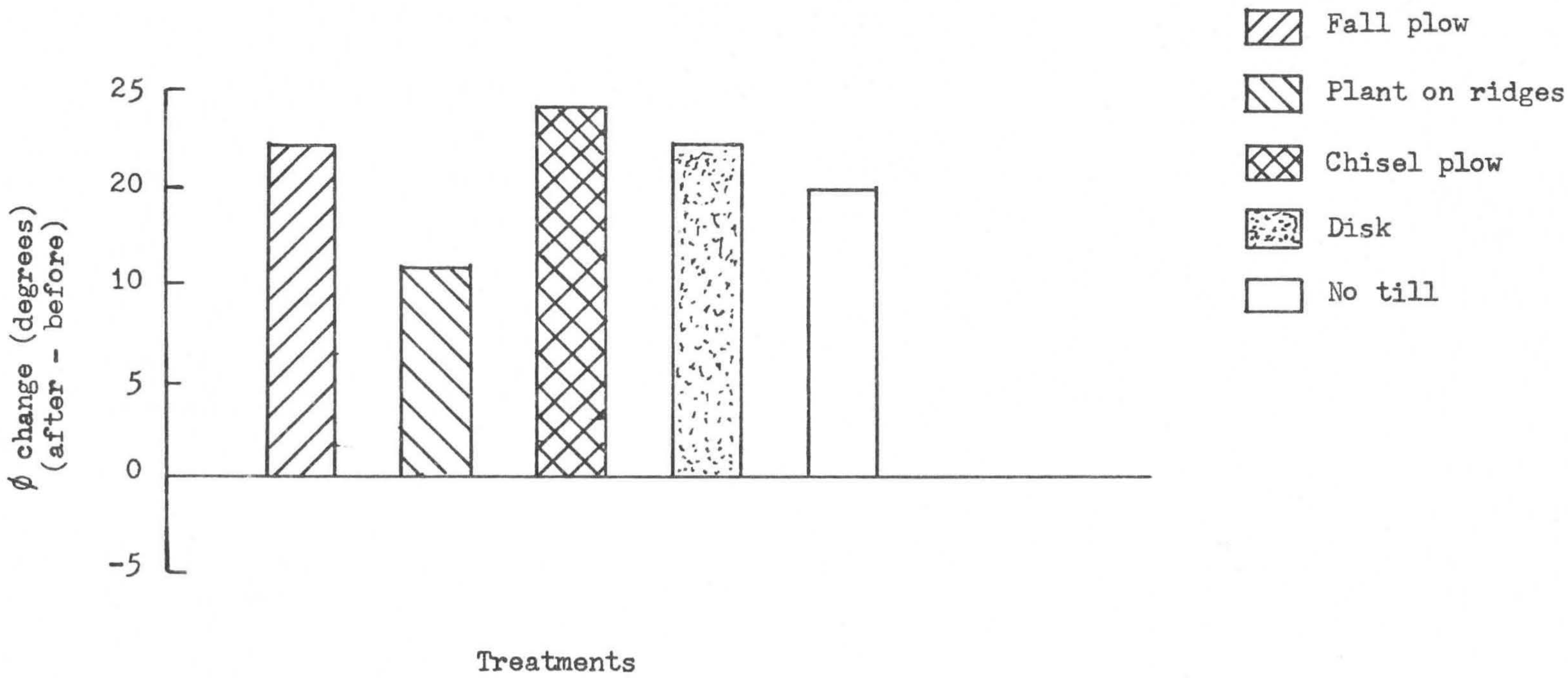

Figure 14. Angle of internal friction changes as affected by tillage-planting operations (furrow)

treatments shows that disk treatment increased the cohesive force between clay particles. An increase in cohesion for fall plow treatment is negligible for all practical purposes.

Angle of internal friction data for tillage systems is given in Table 9 and is shown graphically in Figure 14. All of the values obtained are positive. This means that the angle of internal friction following tillage-planting was greater than angle of internal friction before tillage-planting operations. From Table 9 and Figure 14 the chisel plow treatment produced a greater positive change than any of the other tillage systems. The angle of internal friction found for plow and disk treatments was approximately the same. However, they had different moisture content and different bulk density change.

The results indicate that the tillage systems have an influence in increasing the angle of internal friction of the soil.

In Table 10 the mean changes in cohesion, angle of internal friction, moisture content and bulk density as affected by tillage-planting operations in the row are shown for all tillage systems. Figures 15 and 16 exhibit the cohesion changes and angle of internal friction of the tillage systems. Table 10 shows that the values of cohesion decreased for the plant on ridges, chisel plow and disk treatments. The highest level of such decrease occurred in plant on ridges treatment where the bulk density change (0.034) and the percentage of moisture content change (-0.075) were low. The lowest level of decrease occurred in disk treatment where the bulk density change and percentage of moisture content were 0.003 gms/cc and -0.292% respectively. The same data in Table 10 also shows that the cohesion for fall plow and no till treatments increased.

Table 10. Mean changes in cohesion, angle of internal friction, moisture content and bulk density as affected by tillage-planting operations in row (after - before)

Tillage system	Row[a]			
	C (psi)	ϕ (degrees)	MC (%)	BD (gm/cc)
Fall plow	0.147	4.05	0.655	-0.037
Plant on ridges	-0.100	-4.17	-0.075	0.034
Chisel plow	-0.087	2.25	0.252	0.026
Disk	-0.025	0.29	-0.292	0.003
No till	0.150	2.12	0.775	0.019

[a] C = cohesion, ϕ = angle of internal friction, MC = moisture content, BD = bulk density.

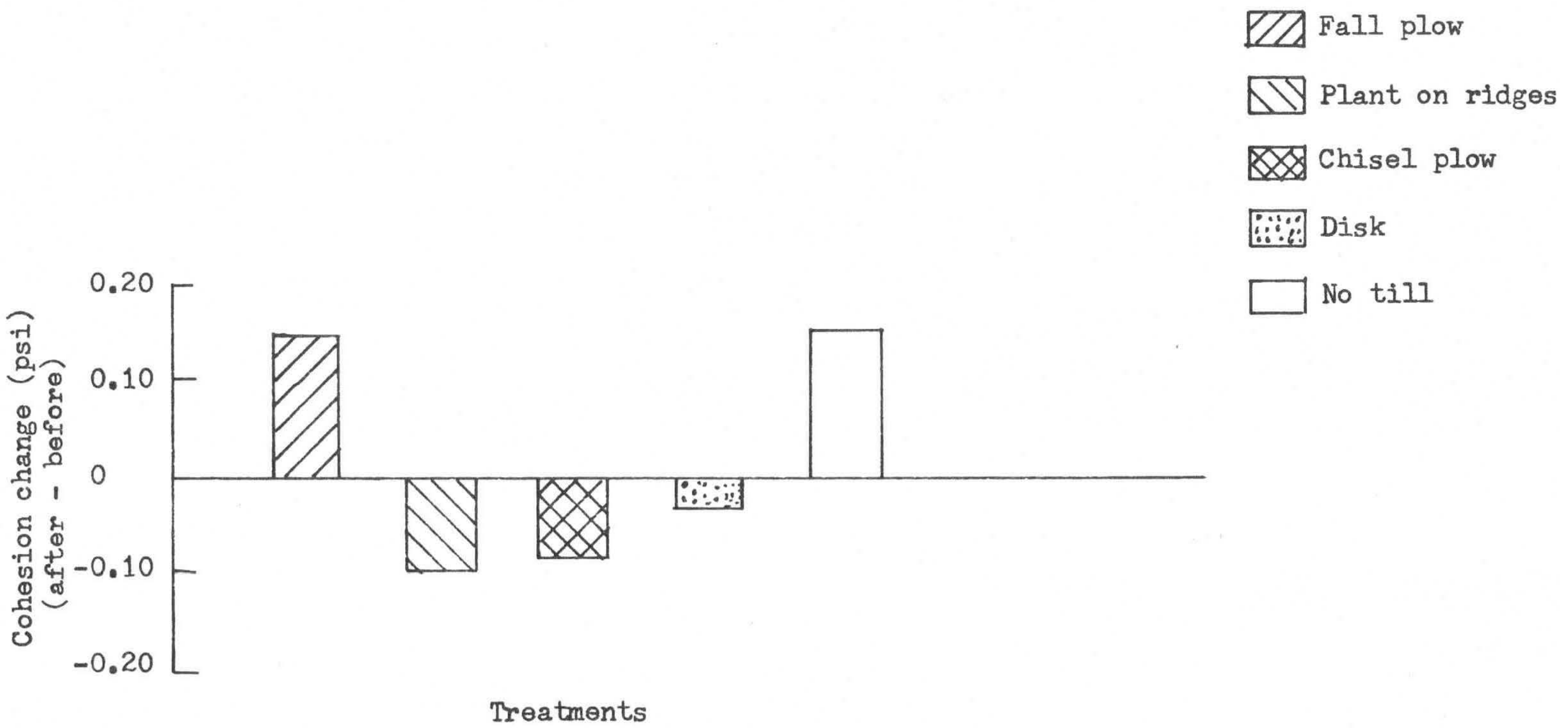

Figure 15. Cohesion changes as affected by tillage-planting operations (row)

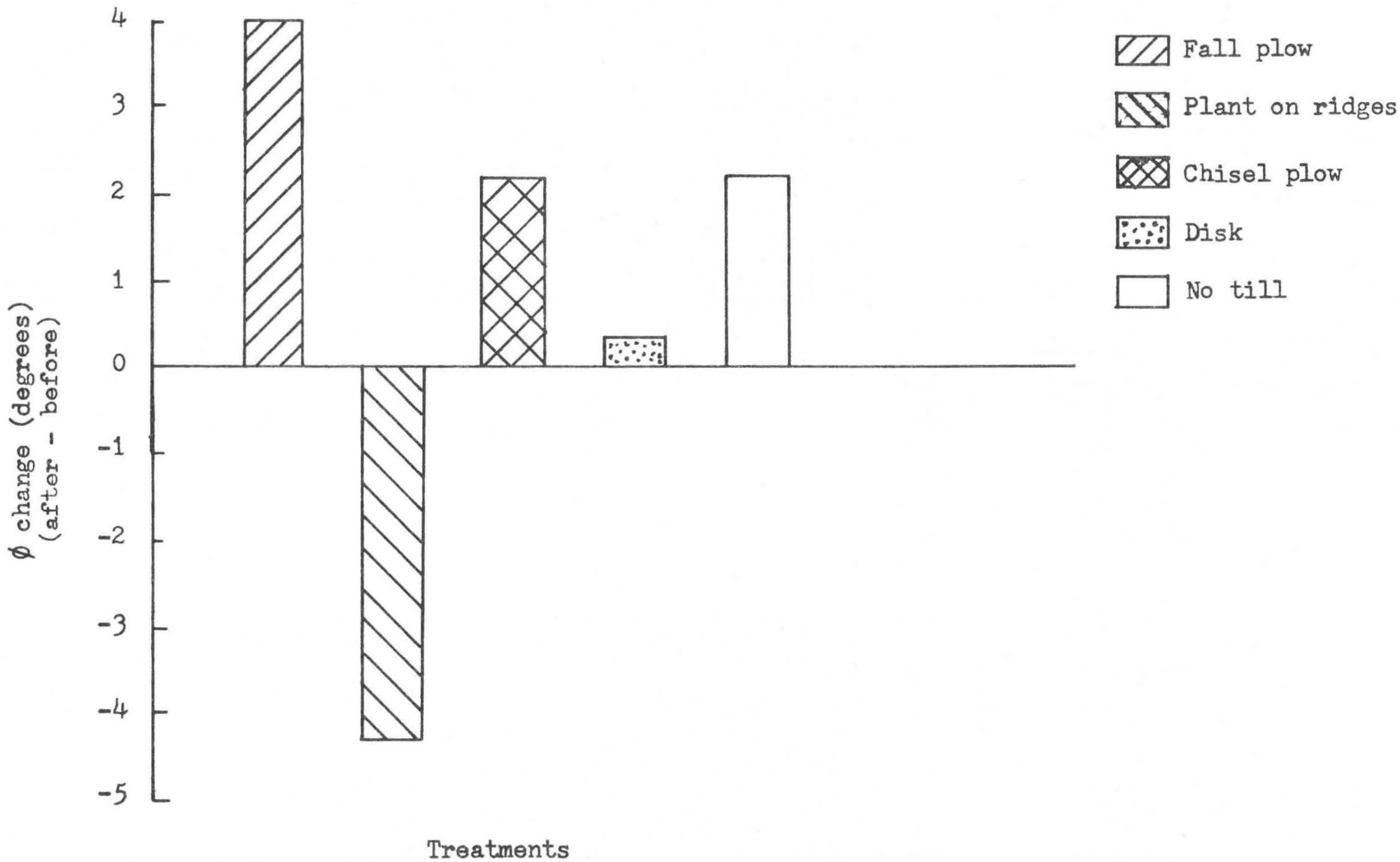

Figure 16. Angle of internal friction changes as affected by tillage-planting operations (row)

A very small difference was recorded between them (Figure 15).

From these data it can be concluded that although plant on ridges, chisel plow and disk treatments help decrease cohesion, the amount of such decrease noted in Figure 15 and Table 8 are of very small magnitude.

Table 10 shows that the values of angle of internal friction change when fall plow, chisel plow, disk and no till treatments increased. The highest level of such increase occurred in fall plow treatment where the bulk density change (-0.037) decreased and moisture content (0.655) increased. Angle of internal friction change decreased for plant on ridges where the bulk density (0.034) increased and moisture content (-0.075) decreased. Only small differences due to chisel plow and no till treatment were obtained for angle of internal friction (Table 10). Larger differences were found between fall plow and disk treatments.

In general, it can be concluded from these data that fall plow, chisel plow and disk treatments help increase the angle of internal friction of the soil. The angle of internal friction of the soil was reduced by approximately 4.17° in plant on ridges treatment.

Tillage systems were not a significant variable in the analysis of variance for cohesion change shown in Table A-13, Appendix A. This indicated that for the cohesion data, there was small variation in cohesion of the soil obtained from plot to plot.

The analysis of variance for angle of internal friction change shown in Table A-14, Appendix A, shows that the tillage systems did not have a significant effect on the angle of internal friction of the soil. This indicated that although tillage systems help increase the angle of internal friction, slight differences were found among them. Highly significant position effect was obtained for angle of internal friction (Table A-14, Appendix A), as would be expected from examination of overall means for furrow (16.8°) and for row position (0.83°). The statistical analysis of the moisture content change and bulk density change shown in Table A-15, Appendix A, indicates that the tillage systems were highly significant for bulk density, as would be expected from the large fluctuations shown in Tables 9 and 10. No significant difference was found for moisture content change. This would be expected since there was small variation between tillage systems.

Cultivation Operations and Physical Measurements

Bulk density

The data for bulk density before cultivation operations are given in Table 11. The table shows the range to be from a low of 1.183 gms/cc in row for fall plow treatment to a high of 1.395 gms/cc in furrow for chisel plow treatment. The bulk density in furrow for fall plow and plant on ridges were approximately 5% higher in the furrow than they were in the row. The bulk density in furrow for chisel plow treatment was 10% higher in the furrow than it was in the row. The bulk density in furrow for disk and no till treatment was slightly higher in the furrow than they were in the row. While the bulk density in furrow had a range of 0.115 in the replicated plots for the depth 0 to 3 inches, it is 0.119 for the 3 to 6 inches depth. The range of the bulk density of all of the tillage systems was approximately 0.190 in furrow and 0.106 in row position. The bulk density in furrow for the depth 0 to 3 inches was 5% higher in the furrow than it was in the row. Likewise, the bulk density in furrow for the

Table 11. Bulk density before cultivation operations

Tillage system	Depth (inches)	Bulk density (gms/cc)	
		Furrow	Row
Fall plow	0 - 3	1.198	1.113
"	3 - 6	1.147	1.119
"	6 - 9	1.205	1.171
"	9 - 12	1.285	1.289
"	12 - 15	1.248	1.218
	Mean	1.217	1.183
Plant on ridges	0 - 3	1.133	1.040
"	3 - 6	1.253	1.189
"	6 - 9	1.277	1.232
"	9 - 12	1.240	1.198
"	12 - 15	1.256	1.271
	Mean	1.232	1.186
Chisel plow	0 - 3	1.071	0.940
"	3 - 6	1.228	1.105
"	6 - 9	1.294	1.134
"	9 - 12	1.084	1.156

Table 11. Continued

Tillage system	Depth (inches)	Bulk density (gms/cc) Furrow	Row
Chisel plow	12 - 15	1.295	1.226
	Mean	1.395	1.112
Disk	0 - 3	0.983	1.115
"	3 - 6	1.266	1.251
"	6 - 9	1.274	1.170
"	9 - 12	1.322	1.288
"	12 - 15	1.291	1.265
	Mean	1.227	1.218
No till	0 - 3	1.114	1.030
"	3 - 6	1.173	1.158
"	6 - 9	1.182	1.284
"	9 - 12	1.270	1.274
"	12 - 15	1.284	1.239
	Mean	1.205	1.197
Overall mean		1.255	1.179

depth 3 to 6 inches was approximately 6% higher in the furrow than it was in the row.

Because of missing values in the data sets, unbalanced design analogous to Henderson's method 1 was used to compute variance components. The analysis of variance for bulk density before cultivation operations is shown in Table B-1, Appendix B. Tillage systems did not have a significant effect on bulk density, as explained by the small difference between tillage system mean. The depth was significant, as may be noted in Table 11. The bulk density of the soil increased with the depth of sampling.

The data for bulk density after cultivation operations are shown in Table 12. The table presents the range to be from a low of 1.152 gms/cc in row for no till treatment to a high of 1.279 gms/cc in furrow for fall plow. The bulk density in furrow for fall plow and chisel plow treatments were approximately 7.5% higher in the furrow than they were in the row. Likewise, the bulk density in furrow for disk and no till treatments were approximately 5.5% higher in the furrow than they were in the row. The bulk density in furrow for plant on ridges was 8% higher in the furrow than it was in the row. While the bulk density in furrow ranged 0.060 in the replicated plots for the depth 0 to 3 inches, it is 0.167 for the 3 to 6 inches depth; furthermore, it is 0.115 for the 0 to 3 inches and 0.251 for the 3 to 6 inches depth in row position. The range of the bulk density of all of the tillage systems was approximately 0.032 in furrow and 0.058 in row position. The bulk density in furrow for the depth 0 to 3 inches was 19.5% higher in the furrow than it was in the row; too, the bulk density in furrow for the depth 3 to 6 inches was 11.2% higher in the furrow than it was in the row. Lesser bulk density difference in furrow

Table 12. Bulk density after cultivation operations

Tillage system	Depth (inches)	Bulk density (gms/cc)	
		Furrow	Row
Fall plow	0 - 3	1.190	1.008
"	3 - 6	1.277	1.026
"	6 - 9	1.264	1.272
"	9 - 12	1.358	1.300
"	12 - 15	1.307	1.289
	Mean	1.279	1.179
Plant on ridges	0 - 3	1.147	0.898
"	3 - 6	1.359	1.074
"	6 - 9	1.241	1.178
"	9 - 12	1.291	1.292
"	12 - 15	1.271	1.339
	Mean	1.262	2.156
Chisel plow	0 - 3	1.207	0.983
"	3 - 6	1.173	1.175
"	6 - 9	1.333	1.162
"	9 - 12	1.299	1.259

Table 12. Continued

Tillage system	Depth (inches)	Bulk density (gms/cc)	
		Furrow	Row
Chisel plow	12 - 15	1.290	1.225
	Mean	1.260	1.161
Disk	0 - 3	1.196	0.993
"	3 - 6	1.317	1.277
"	6 - 9	1.236	1.205
"	9 - 12	1.315	1.301
"	12 - 15	1.312	1.277
	Mean	1.277	1.210
No till	0 - 3	1.173	0.893
"	3 - 6	1.150	1.063
"	6 - 9	1.361	1.205
"	9 - 12	1.289	1.293
"	12 - 15	1.263	1.308
	Mean	1.247	1.152
Overall mean		1.265	1.172

and row position were found for the depth 6 to 9 inches. The bulk density was approximately the same for the depth 9 to 12 and 12 to 15 inches. This would be expected since the cultivation operations do not disturb the soil at this depth. The overall mean in furrow was approximately 7% higher in the furrow than it was in the row.

The analysis of variance for bulk density after cultivation operations given in Table B-2, Appendix B, shows that the tillage systems were not significantly different. The cause of this nonsignificance among tillage systems is due to small bulk density differences among treatments. The effect for position and depth was highly significant. Significance of the main effect position can be explained from the difference between overall mean for furrow and row position. Significance of the main effect depth was caused by large difference between depths. Whenever soil is disturbed by cultivation operations, a variation of this type may be expected. Linear and quadratic for main effect depth were tested significant (Table B-3, Appendix B). It will be observed from Table 12 that the bulk density of the soil increased until it reached a peak value at a certain depth of soil, beyond that, it decreased for the remaining depth of soil. The position x depth interaction was highly significant; this indicates that the position and depth factors did not act independently and the influence of the depth factor on bulk density depended on the level of the position factor.

The data for bulk density change (after - before) cultivation operations are shown in Table 13. To visualize the effects of tillage systems on both the bulk density changes and depth of sampling, Figures 17 and 18 were constructed. Table 13 indicates that chisel plow treatment has a

Table 13. Bulk density change (after - before) cultivation operations

Tillage system	Depth (inches)	Bulk density (gms/cc)	
		Furrow	Row
Fall plow	0 - 3	-0.007	-0.071
"	3 - 6	0.130	-0.093
"	6 - 9	0.058	0.101
"	9 - 12	0.073	0.011
"	12 - 15	0.058	0.063
	Mean	0.062	0.002
Plant on ridges	0 - 3	0.014	-0.142
"	3 - 6	0.105	-0.114
"	6 - 9	-0.035	-0.054
"	9 - 12	0.050	0.093
"	12 - 15	0.009	0.067
"	Mean	0.025	-0.030
Chisel plow	0 - 3	0.136	0.042
"	3 - 6	-0.055	0.070
"	6 - 9	0.039	0.028
"	9 - 12	-0.215	0.103

Table 13. Continued

Tillage system	Depth (inches)	Bulk density (gms/cc)	
		Furrow	Row
Chisel plow	12 - 15	-0.004	-0.001
	Mean	-0.134	0.048
Disk	0 - 3	0.226	-0.122
"	3 - 6	0.051	0.025
"	6 - 9	-0.038	0.034
"	9 - 12	-0.006	0.013
"	12 - 15	0.021	0.011
	Mean	0.047	-0.007
No till	0 - 3	0.059	-0.136
"	3 - 6	-0.022	-0.094
"	6 - 9	0.178	-0.078
"	9 - 12	0.018	0.019
"	12 - 15	-0.020	0.069
	Mean	0.042	-0.044
Overall mean		0.009	-0.006

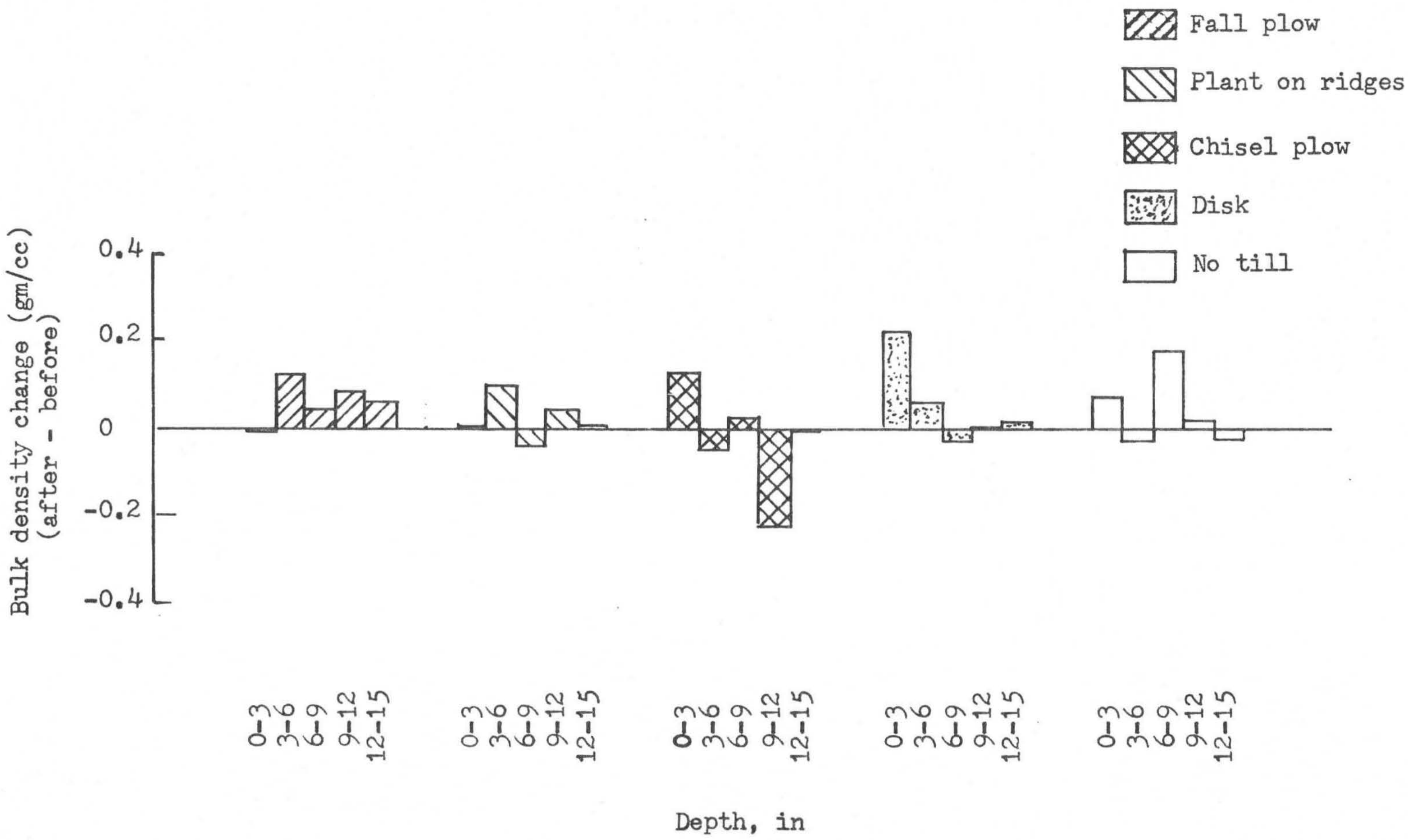

Figure 17. Bulk density changes as affected by cultivation operations in the furrow.

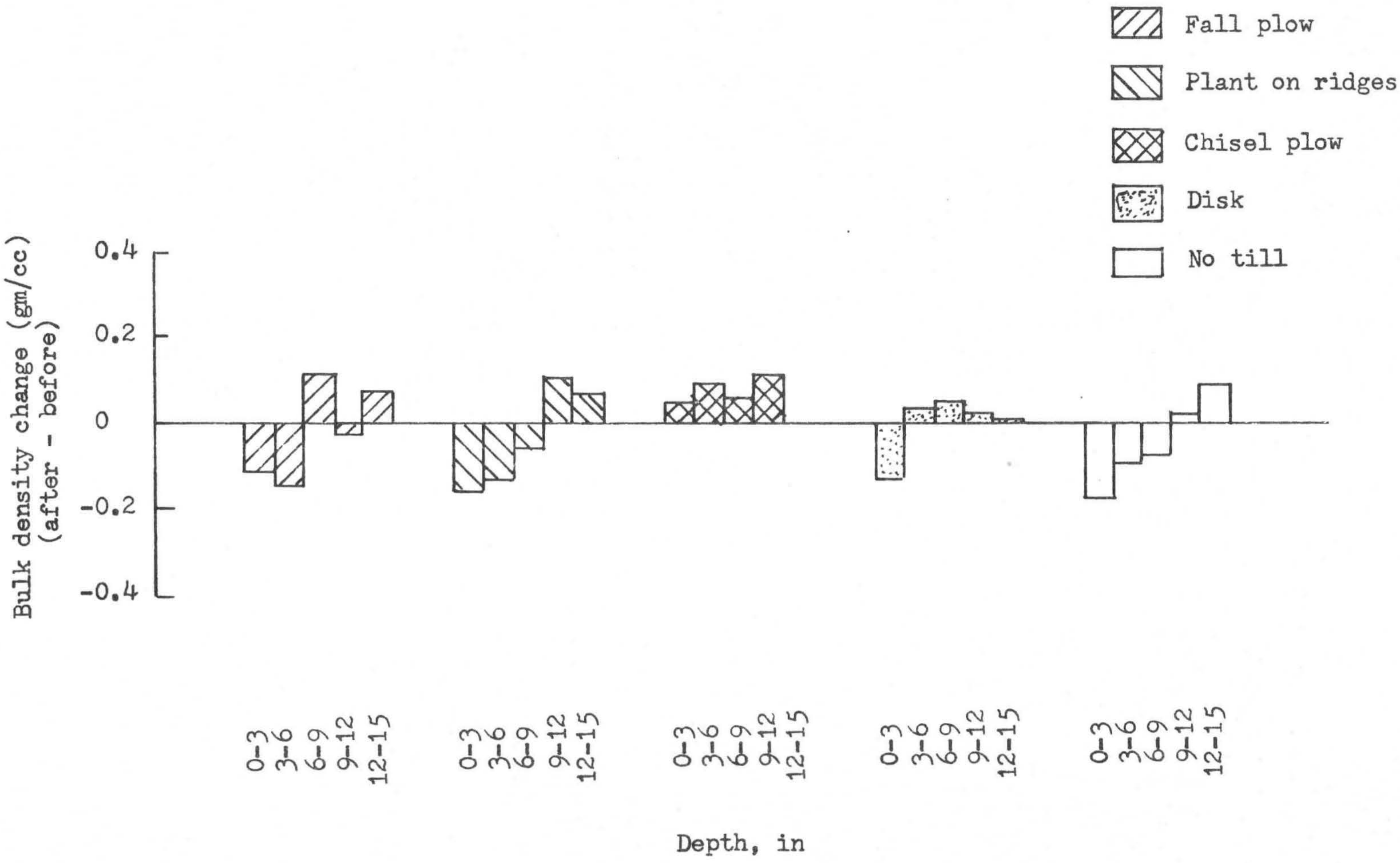

Figure 18. Bulk density changes as affected by cultivation operations in row

small decrease for mean bulk density in furrow position. The remaining tillage systems do not show a decrease for mean bulk density in furrow position. Plant on ridges, disk and no till treatments show a decrease for mean bulk density in row position. The fall plow treatment shows a very small decrease at 0 to 3 inches depth in furrow and at 0 to 3 and 6 to 3 inches depth in row position. The plant on ridges treatment exhibits a small decrease at 0 to 3, 3 to 6 and 6 to 9 inches depth in row position. The chisel plow treatment presents a very small decrease at 3 to 6 inches depth; also, the bulk density decreased at lower depths in furrow position. The disk treatment shows a small decrease at 0 to 3 inches depth in row position; likewise, the bulk density decreased very little at lower depths. The no till treatment indicated a decrease at 0 to 3, 3 to 6 and 6 to 9 inches depth in row position; also, the bulk density decreased very little at 3 to 6 inches depth in furrow position.

The bulk density for the furrow and row position are shown in Figures 17 and 18 to illustrate the small differences in bulk density change existing between the tillage systems. It is likely that a portion of these small differences, directly or indirectly, resulted from the sampling error.

A statistical analysis of data does not indicate a significant difference among tillage systems (Table B-4, Appendix B). This would be expected because of the small difference in bulk density change existing between the tillage systems.

From these data it can be concluded that the cultivation operations had no significant effect on the bulk density of the soil.

Moisture content

The data shown in Table 14 are values of moisture content before cultivation operations. This table indicates the range to be from a low of about 23% mean soil moisture content for no till treatment in row to a high of about 26% for plant on ridges in furrow position; also, the mean soil moisture in row shows a range from 23.19% in no till treatment to 25.92% in plant on ridges treatment. The mean soil moisture in furrow shows a range from 24.52% in chisel plow treatment to 26.75% in plant on ridges. Fall plow treatment showed the highest range of difference (6.86%) in furrow, with about 1.1% from 0 to 6 inches depth. The lowest range of difference (1.80%) was found in disk treatment in row position, with about 0.38% from 0 to 6 inches depth. The overall means of moisture content in furrow was approximately 2% higher in the furrow than it was in the row.

The analysis of variance for moisture content before cultivation operations is shown in Table B-5, Appendix B. The table indicates that the tillage systems did not have a significant effect on moisture content. This would be expected from the small fluctuations among tillage systems. The depth was found to be highly significant. It can be observed from Table 14 that the moisture content of the soil varies with the depth of sampling.

The data shown in Table 15 are values of moisture content after cultivation operations. This table indicates the range to be from a low of about 23% mean soil moisture content for no till treatment in furrow to a high of about 26% for plant on ridges in row position. The mean soil moisture in furrow shows a range from 23.36% in no till treatment to

Table 14. Soil moisture content before cultivation operations

Tillage system	Depth (inches)	Percent moisture content	
		Furrow	Row
Fall plow	0 - 3	27.63	24.08
"	3 - 6	28.78	27.94
"	6 - 9	26.19	25.06
"	9 - 12	23.74	22.68
"	12 - 15	21.92	26.60
	Mean	25.65	25.38
Plant on ridges	0 - 3	29.21	24.42
"	3 - 6	27.59	25.79
"	6 - 9	26.47	27.10
"	9 - 12	25.65	25.97
"	12 - 15	24.81	26.39
	Mean	26.75	25.92
Chisel plow	0 - 3	26.48	23.91
"	3 - 6	26.62	27.86
"	6 - 9	24.27	25.70
"	9 - 12	24.58	25.42

Table 14. Continued

Tillage system	Depth (inches)	Percent moisture content	
		Furrow	Row
Chisel plow	12 - 15	22.66	25.58
	Mean	24.52	25.71
Disk	0 - 3	26.18	24.62
"	3 - 6	24.79	25.00
"	6 - 9	24.61	24.75
"	9 - 12	23.03	23.29
"	12 - 15	25.05	25.09
	Mean	24.73	24.53
No till	0 - 3	27.14	23.18
"	3 - 6	24.53	24.88
"	6 - 9	22.66	21.75
"	9 - 12	24.46	22.58
"	12 - 15	24.69	23.66
	Mean	24.70	23.19
Overall mean		25.27	24.94

Table 15. Soil moisture content after cultivation operations

Tillage system	Depth (inches)	Percent moisture content	
		Furrow	Row
Fall plow	0 - 3	24.92	23.27
"	6 - 3	28.08	23.38
"	6 - 9	25.60	28.62
"	9 - 12	22.97	24.94
"	12 - 15	22.89	23.13
	Mean	24.16	25.07
Plant on ridges	0 - 3	22.36	27.61
"	3 - 6	25.04	26.46
"	6 - 9	25.17	26.97
"	9 - 12	23.18	26.22
"	12 - 15	22.32	24.27
	Mean	23.71	26.31
Chisel plow	0 - 3	28.68	23.06
"	3 - 6	25.95	26.70
"	6 - 9	24.41	26.88
"	9 - 12	22.67	25.21

Table 15. Continued

Tillage system	Depth (inches)	Percent moisture content Furrow	Row
Chisel plow	12 - 15	22.98	23.48
	Mean	23.36	24.03
Disk	0 - 3	24.60	25.54
"	3 - 6	24.89	25.13
"	6 - 9	24.50	24.53
"	9 - 12	21.73	23.06
"	12 - 15	22.82	22.99
	Mean	24.89	25.89
No till	0 - 3	23.49	21.80
"	3 - 6	24.11	25.10
"	6 - 9	22.85	27.04
"	9 - 12	22.72	23.53
"	12 - 15	23.64	22.69
	Mean	23.61	26.30
Overall mean		23.95	25.11

24.89% in fall plow treatment; too, the mean soil moisture in row shows a range from 24.03% in no till treatment to 26.31% in plant on ridges treatment. Fall plow treatment showed the highest range of difference (6.11%) in furrow, with about 3.16% from 0 to 6 inches depth. Furthermore, the chisel plow treatment had a range of about 6%, with 2.64% from 0 to 6 inches depth. The lowest range of difference (1.39%) was found in no till treatment in furrow position, with about 0.62% from 0 to 6 inches depth. The moisture content for fall plow treatment in furrow for fall plow and chisel plow treatments was 4% lower in the furrow than it was in the row. The moisture content for plant on ridges in furrow was 10% lower in the furrow than it was in the row; likewise, it was 2.5% and 3.2% lower in the furrow than it was in the row for disk and no till treatment. The overall means of moisture content in row was approximately 5% higher in the row than it was in the furrow.

From these data it should be noted that the moisture content of the soil was greater in the row position than in the furrow position at all tillage system plots. This indicates that moisture was lost from the stirred soil.

An analysis of variance for moisture content after cultivation operations was computed and the results are shown in Table B-6, Appendix B. The tillage systems were not found to be significant, as would be expected from examination of tillage system means which were approximately within a 3% range of all treatments. The main effect for position was significant. The significance arises from the difference of the moisture content of the soil which was greater in the row position than in the furrow. The mean effect for depth was highly significant. This would be noted since the moisture content of soil decreases with the depth of sampling (Table 15). Linear, quadratic and lack of fit were tested significant (Table B-7, Appendix B). This means that the data for moisture content of the soil increased until it got to a maximum value at a certain depth of soil beyond which it tended to decrease for the remaining depth of soil.

The data for soil moisture content change (after - before) cultivation operations are given in Table 16. The change relationship is given for the difference of after cultivation and before cultivation. This procedure gives negative values when the cultivation operation decreased the moisture content and positive values when it increased the moisture content.

Data in Table 16 shows the range to be from a low of -3.13% mean soil moisture content in furrow for plant on ridges treatment to a high of 0.94% in row for no till treatment. Also, the mean moisture content change in furrow had a range from -3.13% in plant on ridges treatment to -0.45% in chisel plow treatment. The mean moisture content change in row had a range from 0.94% in no till treatment to -0.42% in chisel plow treatment.

To visualize the effect of cultivation operations on both the moisture content changes and depth of sampling, Figures 19 and 20 were made. The moisture content changes presented in these figures are indicative of the moisture content of the different tillage systems. The moisture content change for furrow position exhibited in Figure 19 shows the tendency of cultivation operations to promote drying rates. In chisel plow, fall plow, disk and no till treatments, the range of soil moisture content changes shown in Figure 19 was smaller than the plant on ridges treatments.

Table 16. Soil moisture content change (after - before) cultivation operations

Tillage system	Depth (inches)	Percent moisture content	
		Furrow	Row
Fall plow	0 - 3	-2.70	-1.44
"	3 - 6	-0.70	1.44
"	6 - 9	-0.59	3.55
"	9 - 12	-0.77	1.84
"	12 - 15	0.97	-3.03
	Mean	-0.76	0.62
Plant on ridges	0 - 3	-6.84	3.19
"	3 - 6	-2.54	0.66
"	6 - 9	-1.30	-0.13
"	9 - 12	-2.46	0.24
"	12 - 15	-2.48	-2.11
	Mean	-3.13	0.47
Chisel plow	0 - 3	-0.80	-0.85
"	3 - 6	0.33	-1.15
"	6 - 9	0.13	1.18
"	9 - 12	-1.91	1.09

Table 16. Continued

Tillage system	Depth (inches)	Percent moisture content Furrow	Row
Chisel plow	12 - 15	0.02	-2.10
	Mean	-0.45	-0.42
Disk	0 - 3	-1.57	0.91
"	3 - 6	0.10	0.12
"	6 - 9	-0.11	-0.21
"	9 - 12	-1.29	-0.23
"	12 - 15	-2.23	-1.78
	Mean	-1.02	-0.17
No till	0 - 3	-3.65	-1.37
"	3 - 6	-0.42	0.21
"	6 - 9	-0.19	5.29
"	9 - 12	-1.74	0.95
"	12 - 15	-1.04	0.67
	Mean	-1.33	0.94
Overall mean		-1.34	0.28

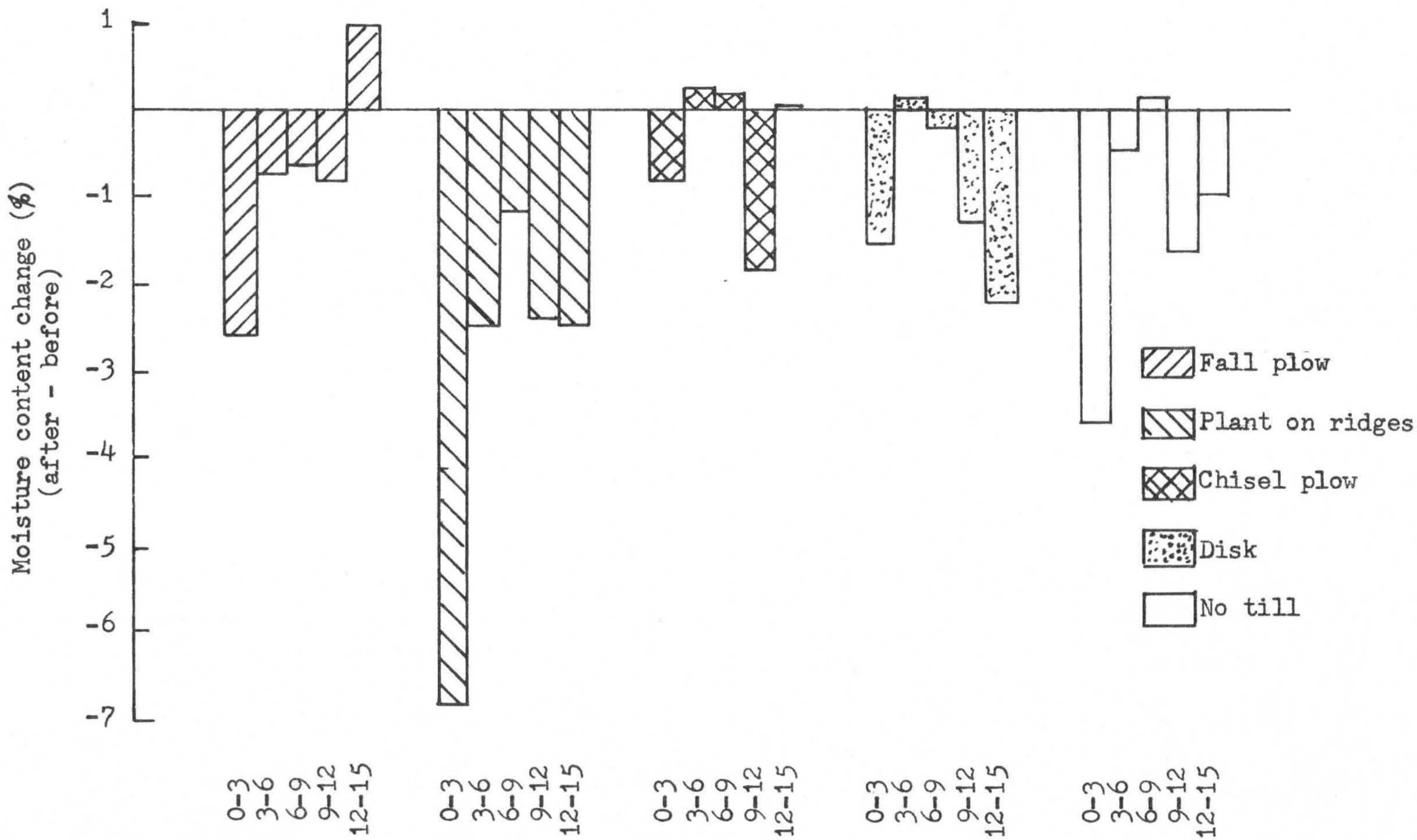

Figure 19. Moisture content changes as affected by cultivation operations in the furrow

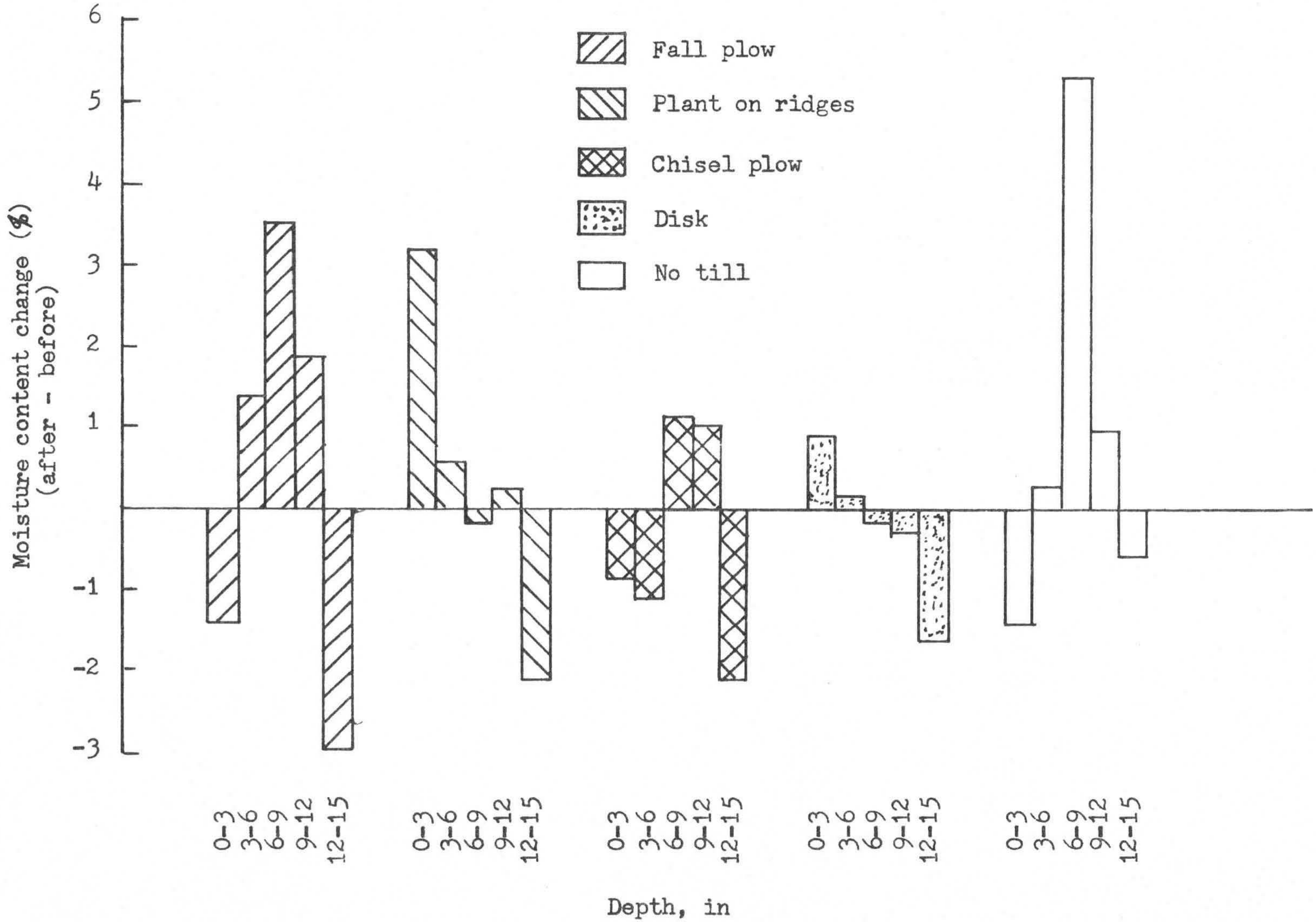

Figure 20. Moisture content changes as affected by cultivation operations in the row

These results, while too limited to permit definite conclusion, indicate that the variation of soil moisture found between the tillage systems was not essentially brought about by the cultivation operations on any of the tillage systems studied. The moisture content changes in row position shown in Figure 20 were not uniform on any of the tillage systems. Since the cultivation operation did not disturb the row, it could be a result of uncontrolled factors, such as moisture stress in the plant, and position of sampling in respect to the plant. The driest place in the field is under a corn plant.

Analysis of variance for soil moisture content change (after - before) is given in Table B-8, Appendix B. The statistical analysis shows that the tillage systems effects are not significant. Nonsignificance arises from the small differences among treatment means. The main effect for position was significant. The mean value for furrow (-0.34%) was smaller than in row (0.28%). The main effect for depth was highly significant. This would be expected since the moisture content changes varied with the depth of sampling. The average moisture content changes obtained from plots in the upper depths were different from those obtained from the lower depth.

From these data it can be concluded that the changes in moisture content were of small magnitude. The use of this variable as index for measuring effect of cultivation operations on moisture content of soil is complicated because of the many factors which affect moisture content. The cultivation operations did not have a clear effect on the moisture content of the soil.

Cone index

The data for cone index before cultivation operations are pointed out in Table 17. The table indicates the cone indexes for the three different depths of 0 to 7, 14 and 21 inches with respect to position (furrow and row) and tillage systems. While the cone index in furrow ranged 31.51 in the replicated plots for the depth 0 to 7 inches, it is 9.80 for the 14 inches and 10.55 for the 21 inches depth. The cone index at 0 to 7 inches depth was 14.9% lower at 0 to 7 inches depth than it was at 14 inches depth. The cone index at 0 to 7 inches depth was 30% higher at 0 to 7 inches depth than it was at 21 inches depth. The fall plow treatment is different with 76.33 for 0 to 7 inches depth and the range of difference in cone index is 53.99. It is 57.04 for plant on ridges, 53.64 for chisel plow, 60.54 for disk and 49.74 for no till treatment. The range of difference of all the tillage systems is 14.85. The highest mean value of cone index in furrow position was reached in no till treatment (98.39). The lowest mean value was found in fall plow treatment (80.12). The data for cone index before cultivation operations in row position (Table 17) indicate that the fall plow treatment is different with 74.42 for 0 to 7 inches depth and its range of difference is 55.64. It is 59.24 for plant on ridges, 56.04 for chisel plow, 65.54 for disk and 50.74 for no till treatment. The highest mean value of cone index in row position was obtained in plant on ridges (93.86). The lowest mean value was reached in fall plow treatment (79.35). The overall means of cone index for furrow and row position were 92.33 and 87.58 respectively.

The analysis of variance cone index before cultivation operations is shown in Table B-9, Appendix B. Significant cone index differences

Table 17. Mean cone index before cultivation operations

Tillage system	Depth (inches)	Cone index (psi)	
		Furrow	Row
Fall plow	0 - 7	78.23	74.42
"	14	107.24	109.64
"	21	54.90	54.00
	Mean	80.12	79.35
Plant on ridges	0 - 7	105.84	97.03
"	14	112.24	121.84
"	21	57.30	62.70
	Mean	95.13	93.86
Chisel plow	0 - 7	105.64	79.23
"	14	109.24	111.64
"	21	58.00	55.60
	Mean	90.96	82.15
Disk	0 - 7	113.04	102.64
"	14	116.84	119.64
"	21	61.30	54.10

Table 17. Continued

Tillage system	Depth (inches)	Cone index (psi)	
		Furrow	Row
Disk	Mean	97.06	92.12
No till	0 - 7	115.04	91.83
"	14	114.44	115.04
"	21	65.70	64.30
	Mean	98.39	90.39
Overall mean		92.33	87.58

associated with tillage systems occurred when the fall plow and chisel plow treatments were less than average of 89.95 and the remaining tillage systems were greater than the average of 89.95. The main effect for position was significant. The significance arises from the overall mean of cone index for row position which was less than the overall mean for furrow position. The main effect for depth was highly significant, as would be expected from the large depth-to-depth differences shown in Table 17.

The data for cone index after cultivation operations are shown in Table 18. The table indicates the cone index for the three different depths with respect to position (furrow and row) and tillage systems. While the cone index in furrow had a range of 21.81 in the replicated plots for the depth 0 to 7 inches, it is 25.01 for the 14 inches and 15.40 for the 21 inches depth. The cone index in row had a range of 35.41 for the depth 0 to 7 inches, it was 15.01 for the 14 inches and 9.20 for the 21 inches depth. The cone index in furrow was 5% greater in the furrow than it was in the row. The fall plow treatment is different with 83.23 (furrow) for 0 to 7 inches depth and with a range of difference of 53.04. It is 47.14 for plant on ridges, 49.64 for chisel plow, 60.64 for disk and 55.24 for no till treatment. The fall plow treatment is also different in row position with 77.03 for 0 to 7 inches depth and with a range of difference of 33.41. It is 48.74 for plant on ridges, 32.93 for chisel plow, 41.74 for disk and 49.14 for no till treatment. The highest overall mean (furrow and row) of cone index was found in disk treatment (89.17). The lowest overall mean of cone index was reached in chisel plow treatment (83.82).

Table 18. Mean cone index after cultivation operations

Tillage system	Depth (inches)	Cone index (psi)	
		Furrow	Row
Fall plow	0 - 7	83.23	77.03
"	14	118.24	110.44
"	21	65.20	55.80
	Mean	88.89	81.09
Plant on ridges	0 - 7	105.24	102.64
"	14	105.24	101.44
"	21	58.10	53.90
	Mean	89.52	85.99
Chisel plow	0 - 7	99.63	82.43
"	14	111.14	95.43
"	21	61.50	52.50
	Mean	90.86	76.79
Disk	0 - 7	110.44	112.44
"	14	93.23	108.44
"	21	49.80	60.70

Table 18. Continued

Tillage system	Depth (inches)	Cone index (psi)	
		Furrow	Row
Disk	Mean	84.49	93.86
No till	0 - 7	111.04	95.63
"	14	102.04	100.64
"	21	55.80	51.50
	Mean	89.62	82.59
Overall mean		88.68	84.06

The analysis of variance for cone index after cultivation operations is shown in Table B-10, Appendix B. The mean cone index was 86.37 psi; there was not a significant tillage response. The main effect for depth was highly significant. One might expect this to be true since the differences were generally greater. Linear and quadratic effect of the depth were tested highly significant (Table B-11, Appendix B). It will be observed from the data in Table 18 that the cone index of the soil increased until it arrived at a maximum value at 14 inches depth of soil beyond which it decreased for the remaining depth of soil. The tillage system x depth interaction was highly significant which indicates that the tillage system and depth effects are not additive and are not independent of one another. The influence of the depth factor on cone index depended on the level of the tillage system.

The data for cone index change (after - before) cultivation operations are shown in Table 19. The same data for cone index in furrow and row position are depicted graphically in Figures 21 and 22. The cone index change is given for the difference between after cultivation and before cultivation. This procedure gives negative values of the variable cone index when the cultivation operations decreased the magnitude and positive values when it increased the values. Table 19 indicates that the fall plow treatment is notably different with increased values in furrow and row position. An increase in the cone index following mechanical cultivations on a plow plot seems not to be reasonable in the 0 to 7 inches layer. However, moisture content changes might be responsible. This may also be partly due to the physical mixing by plowing at 0 to 7 inches depth. Disk and no till treatments show a decrease at the lower depths.

Table 19. Mean cone index change (after - before) cultivation operations

Tillage system	Depth (inches)	Cone index (psi)	
		Furrow	Row
Fall plow	0 - 7	12.00	2.60
"	14	11.00	0.80
"	21	20.60	3.60
	Mean	14.53	2.33
Plant on ridges	0 - 7	- 0.20	5.60
"	14	- 7.00	-20.40
"	21	1.60	-17.60
	Mean	- 1.86	-10.80
Chisel plow	0 - 7	- 6.00	3.20
"	14	2.20	-16.20
"	21	7.00	- 6.20
	Mean	1.06	- 6.40
Disk	0 - 7	- 2.60	9.80
"	14	-23.60	-11.20

Table 19. Continued

Tillage system	Depth (inches)	Cone index (psi)	
		Furrow	Row
Disk	21	-23.00	13.20
	Mean	-16.40	- 3.93
No till	0 - 7	- 4.00	3.80
"	14	-12.40	-14.40
"	21	-19.80	-25.61
	Mean	-12.07	-12.07
Overall mean		- 2.94	- 4.60

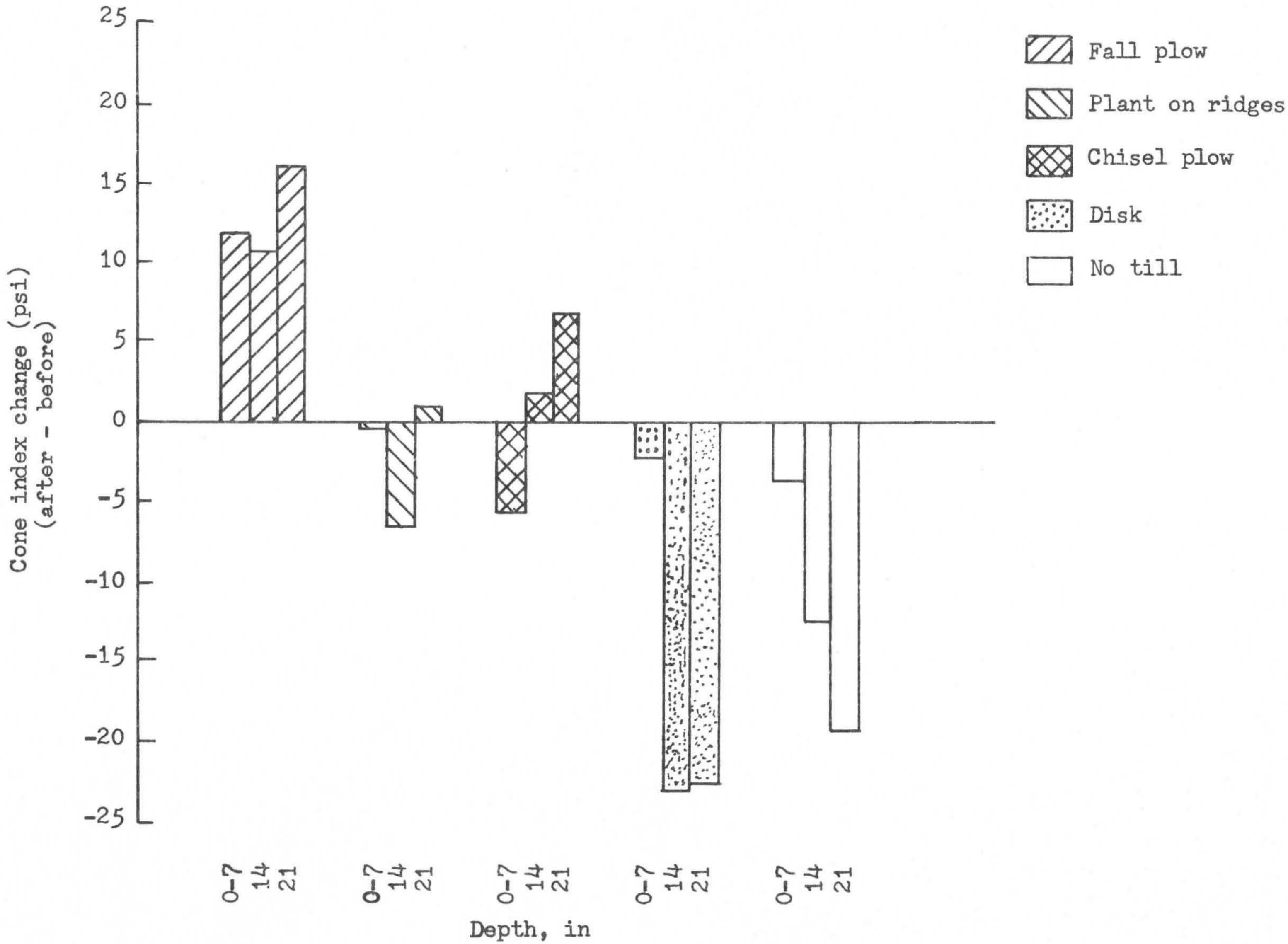

Figure 21. Cone index as affected by cultivation operations in the furrow

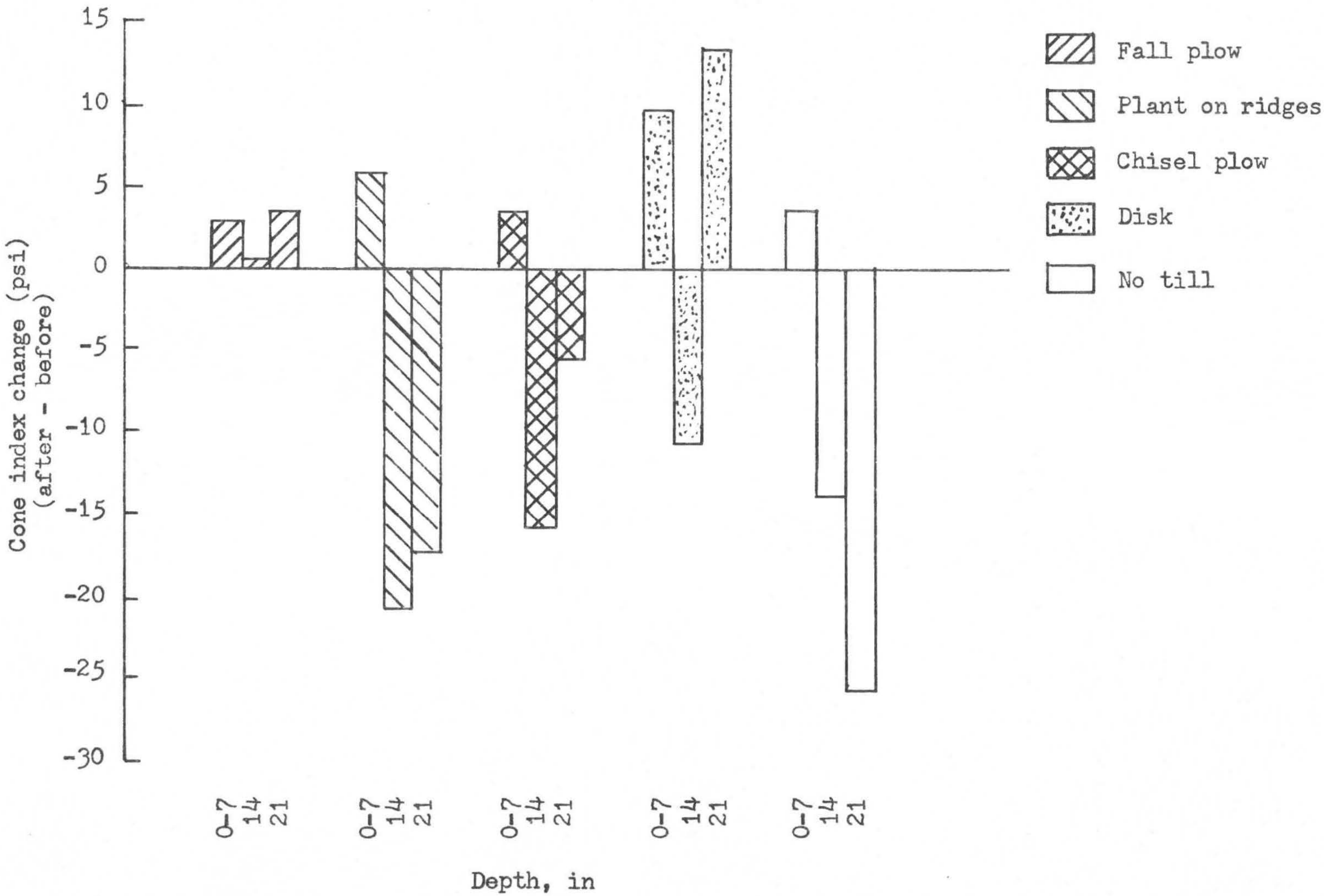

Figure 22. Cone index as affected by cultivation operations in the row

The erratic results obtained for these treatments could possibly be due to the variation of moisture content of the soil in the entire profile when the plots were cultivated.

The mean cone index resulting from no till treatment for furrow and row position were the same. Disk treatment has the highest cone index changes (furrow) followed by no till treatment. Plant on ridges has the lowest cone index changes (furrow) followed by chisel plow (row). In plant on ridges treatment, the row has a larger cone index change than the furrow position. The chisel plow treatment has an increase of cone index in furrow but it decreases in row position. The disk treatment has a decrease of cone index in furrow but it increases in row position. The overall mean (furrow and row) cone index of all of the tillage systems for fall plow was 8.34, -6.33 for plant on ridges, -2.66 for chisel plow, -6.22 for disk and -12.07 for no till treatment. These overall means indicate that the differences were found in fall plow, plant on ridges, chisel plow and disk plots as compared to no till plot. These differences may not be significant. The overall mean of the cone index change for furrow and row position were -2.94 and -4.60 respectively.

The analysis of variance for cone index change (after - before) due to cultivation operations is shown in Table B-12, Appendix B. Although some differences were observed between tillage systems as compared to no till, the tillage systems were not found to have significant effect on cone index. An orthogonal comparison showed that the fall plow treatment versus all other tillage systems was significant. The significance arises from the increased cone index in the fall plow plot.

It may be concluded that the mechanical cultivations tend to promote a decrease of cone index for furrow position in the 0 to 7 inches layer. The effect can be seen in plant on ridges, chisel plow, disk and no till treatment. An increased cone index on the fall plow plots; moisture content change probably was directly or indirectly responsible. Linear and quadratic effect of the depth were tested significant.

Cohesion and angle of internal friction

The data for cohesion and angle of internal friction before cultivation operations are shown in Table 20. The highest mean value of cohesion in furrow position was reached in chisel plow treatment (1.32). The lowest mean value of cohesion in furrow position was found in no till treatment (1.05). The highest mean value of cohesion in row position was reached in plant on ridges (1.64) and the lowest mean value was found in disk treatment (1.02). The range of cohesion of all of the tillage systems for furrow and row position was 0.26 and 0.62 respectively. The cohesion in row was 11% greater than it was in the furrow.

An analysis of variance of cohesion before cultivation operations is shown in Table B-13, Appendix B. The tillage systems were not significant, as would be expected from the small differences among treatment mean. The mean effect for position was not significant. The nonsignificance arises from a small difference between furrow and row position.

The highest mean value of angle of internal friction in furrow position was found in no till treatment (55.15°) and the lowest mean value was reached in chisel plow treatment (49.46°). The highest mean value of angle of internal friction in row was found in fall plow (54.97°) and the

Table 20. Mean values of cohesion (C) and angle of internal friction (ϕ) before cultivation operations

Tillage system	C (psi)		ϕ (degrees)	
	Furrow	Row	Furrow	Row
Fall plow	1.14	1.40	53.92	54.97
Plant on ridges	1.12	1.64	50.86	50.88
Chisel plow	1.32	1.34	49.46	54.11
Disk	1.22	1.02	54.66	51.25
No till	1.06	1.22	55.15	53.80
Overall mean	1.17	1.32	52.81	53.00

lowest mean value was reached in disk treatment (51.25°). The range of angle of internal friction of all of the tillage systems for furrow position was 5.69° and 4.09° for row position. The angle of internal friction in row was 0.5% greater in the row than it was in the furrow.

An analysis of variance for angle of internal friction before cultivation operations is given in Table B-14, Appendix B. There were no significant differences among tillage treatments. This would be explained from the small variation between treatment mean shown in Table 20. The position was not significant. This would be expected since the difference between furrow and row was of a very small magnitude.

The mean values of cohesion and angle of internal friction after cultivation operations is shown in Table 21. The highest mean value of cohesion in furrow position was found in plant on ridges (1.44) and the lowest mean value was reached in fall plow treatment (1.10). The highest mean value of cohesion in row position was found in no till treatment (1.30) and the lowest mean value was reached in disk treatment (0.96). The range of cohesion of all of the tillage systems for furrow was 0.04 and 0.34 for row position. The cohesion in furrow was 8.5% higher in the furrow than it was in the row.

An analysis of variance of cohesion after cultivation operations is shown in Table B-15, Appendix B. Tillage systems were not found to be significant. The nonsignificance arises from the small variation among treatment mean. The mean effect for position was not significant, as would be expected from examination of mean value for furrow and row position.

The highest mean value of angle of internal friction in furrow

Table 21. Mean values of cohesion (C) and angle of internal friction (ϕ) after cultivation operations

Tillage system	C (psi)		ϕ (degrees)	
	Furrow	Row	Furrow	Row
Fall plow	1.10	1.12	54.79	59.79
Plant on ridges	1.44	1.12	57.65	58.20
Chisel plow	1.38	1.20	55.49	59.67
Disk	1.14	0.96	55.31	58.34
No till	1.18	1.30	61.14	54.12
Overall mean	1.24	1.14	56.88	58.02

position was found in plant on ridges treatment (57.65°) and the lowest mean value was reached in fall plow treatment (54.79°). The highest mean value of angle of internal friction in row was found in fall plow treatment (59.79°) and the lowest mean value was found in no till treatment (54.12°). The range of angle of internal friction of all of the tillage systems for furrow position was 2.86° and 5.67° for row position. The angle of internal friction in row was 2% greater in the row than it was in the furrow.

An analysis of variance for angle of internal friction after cultivation operations is shown in Table B-16, Appendix B. Tillage systems were not significant. This would be explained from the small differences among treatment means. The position was not significant, as would be expected from the small differences between mean values for furrow and row position.

In Table 22 the mean changes in cohesion, angle of internal friction, moisture content and bulk density as affected by cultivation operations in furrow are presented. To visualize the effect of cultivation operations on both the cohesion and angle of internal friction in furrow position, Figures 23 and 24 were constructed. The cohesion mean value from fall plow and disk treatment decreased. It is indicated for the negative values in Table 22. The plant on ridges, chisel plow and no till treatment, on the other hand, increased as shown by positive values in Table 22. The reduction of cohesion from fall plow and disk treatment were of a very small magnitude. The amount of increased cohesion was of a very small magnitude for chisel plow and for no till treatment. The bulk density of the soil decreased and moisture content increased for each

Table 22. Mean changes in cohesion, angle of internal friction, moisture content and bulk density as affected by cultivation operations in furrow (after - before)

Tillage system	Furrow[a]			
	C (psi)	ϕ (degrees)	MC (%)	BD (gm/cc)
Fall plow	-0.04	0.87	0.89	-0.239
Plant on ridges	0.32	6.79	4.80	-0.191
Chisel plow	0.06	6.02	3.24	-0.291
Disk	-0.08	0.64	1.94	-0.227
No till	0.12	5.98	0.08	-0.176

[a]C = Cohesion, ϕ = Angle of internal friction, MC = Moisture content, BD = Bulk density.

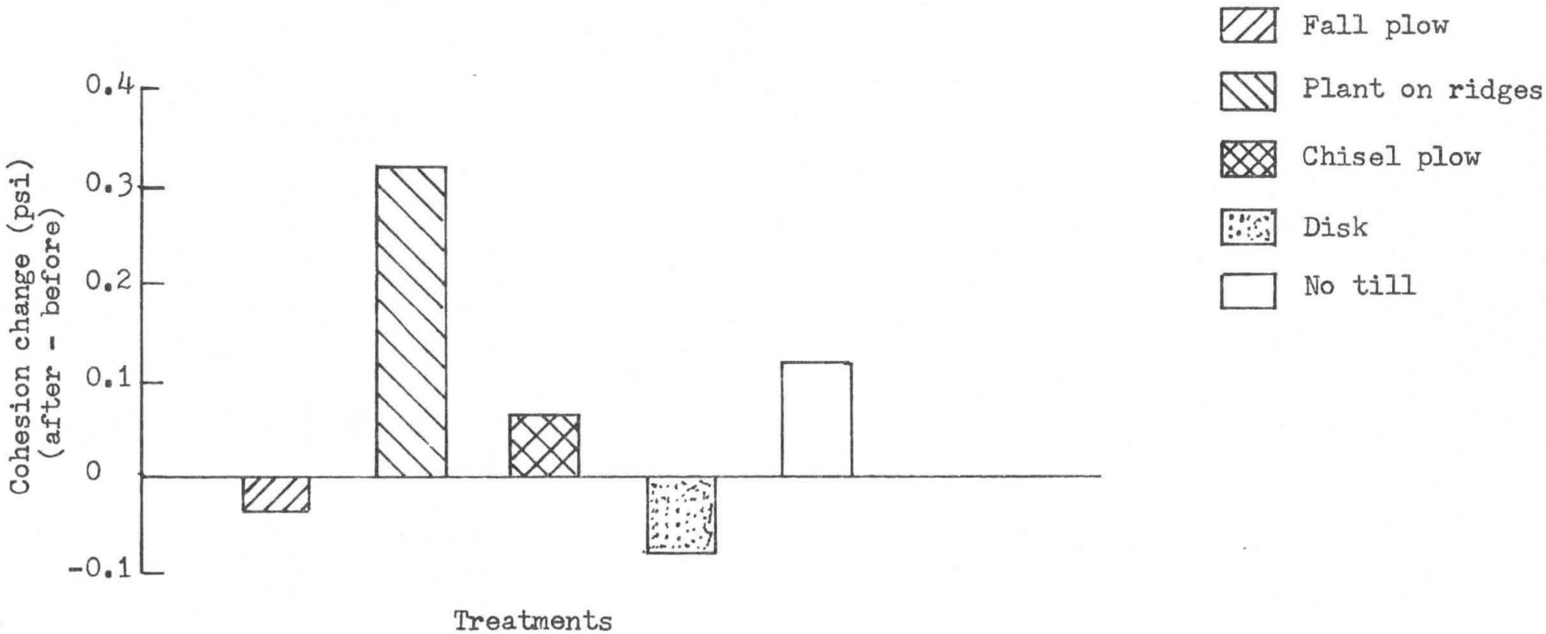

Figure 23. Cohesion changes as affected by cultivation operations in the furrow

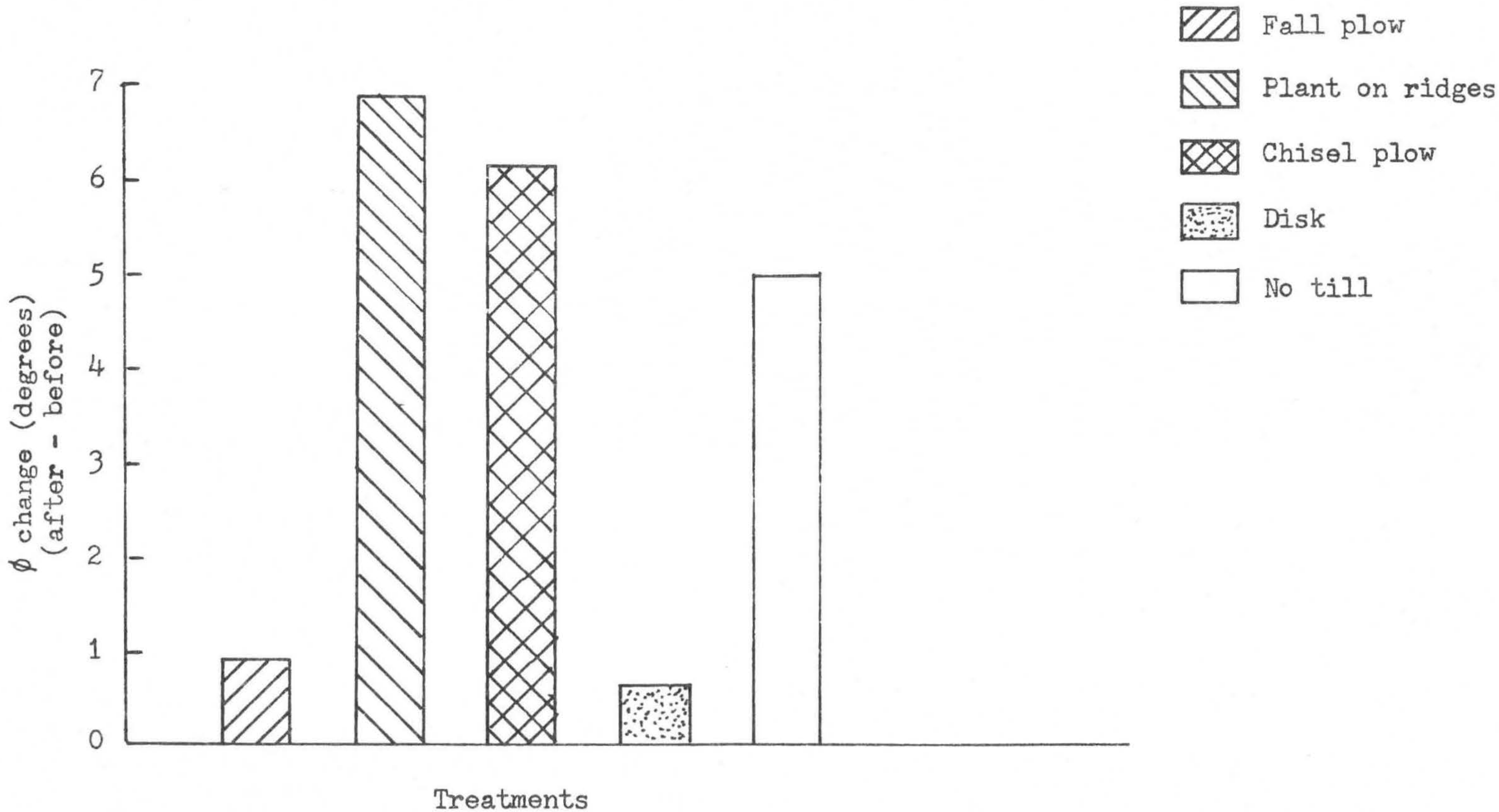

Figure 24. Angle of internal friction changes as affected by cultivation operations in the furrow

tillage system.

A statistical analysis of the cohesion data indicates that the tillage systems were not significant (Table B-17, Appendix B). The nonsignificance arises from the small differences among treatment means, shown in Table 22.

The data for Table 22 indicate that the angle of internal friction increased for all tillage treatments. The highest mean value of the angle of internal friction was reached in plant on ridges treatment and the lowest mean value was found in fall plow treatment. Angle of internal friction in no till treatment was approximately 12% greater than it was in the disk treatment. The change in the angle of internal friction in plant on ridges and chisel plow was greater than the other tillage systems.

A statistical analysis of change of angle of internal friction data indicates that the tillage systems were not significant (Table B-18, Appendix B. The nonsignificance can be explained from the small differences among plant on ridges, chisel plow and no till treatment means.

The results indicate that the cultivation operation had no effect on the values of cohesion of the soil for furrow position in the treatment plots. A statistical significance was not shown in the tillage system studied. Although statistical significance was not found in the tillage systems, the cultivation operations performed on the treatment plots seem to be an influence in increasing the angle of internal friction of the soil in furrow position.

In Table 23 the mean change in cohesion, angle of internal friction, moisture content and bulk density as affected by cultivation operations in

Table 23. Mean changes in cohesion, angle of internal friction, moisture content and bulk density as affected by cultivations in row (after - before)

Tillage system	Row[a]			
	C (psi)	ϕ (degrees)	MC (%)	BD (gm/cc)
Fall plow	-0.28	4.820	6.010	-0.277
Plant on ridges	-0.52	7.316	1.562	-0.093
Chisel plow	-0.14	5.566	4.810	-0.298
Disk	-0.06	7.096	0.906	-0.214
No till	0.08	0.322	2.678	-0.189

[a]C = Cohesion, ϕ = Angle of internal friction, MC = Moisture content, BD = Bulk density.

row are shown for all treatments. Figures 25 and 26 illustrate the cohesion change and angle of internal friction of the treatments. Table 23 shows a decrease in cohesion for fall plow, plant on ridges, chisel plow and disk treatments, while the no till treatment shows an increase in cohesion. Although the row area was not disturbed, there was some soil thrown into this area with the cultivation operations. For this reason one would expect the row area to show a slight decrease in cohesion and an increase in angle of internal friction of the soil. The amount of increased cohesion in no till treatment was of a very small magnitude. The bulk density of the soil decreased and moisture content increased for all tillage systems. The angle of internal friction (Table 23) increased for all tillage systems. The highest mean value of angle of internal friction was found in plant on ridges treatment and the lowest mean value was reached in no till treatment. The angle of internal friction in plant on ridges and disk treatment was greater than the other tillage systems.

The main effect for position was not found to be significant when the cohesion and angle of internal friction data were statistically analyzed (Tables B-17, B-18, Appendix B). The nonsignificance originates from examination of overall mean for cohesion and angle of internal friction in furrow and row position. The differences were of a small magnitude. The statistical analysis of the moisture content and bulk density change shown in Table B-19, Appendix B, indicates that tillage systems and main effect position were not significant. The nonsignificance arises from the small treatment differences shown in Tables 22 and 23.

Since the row area was not tilled, the cultivation operations had an indirect effect on the values of cohesion and angle of internal friction

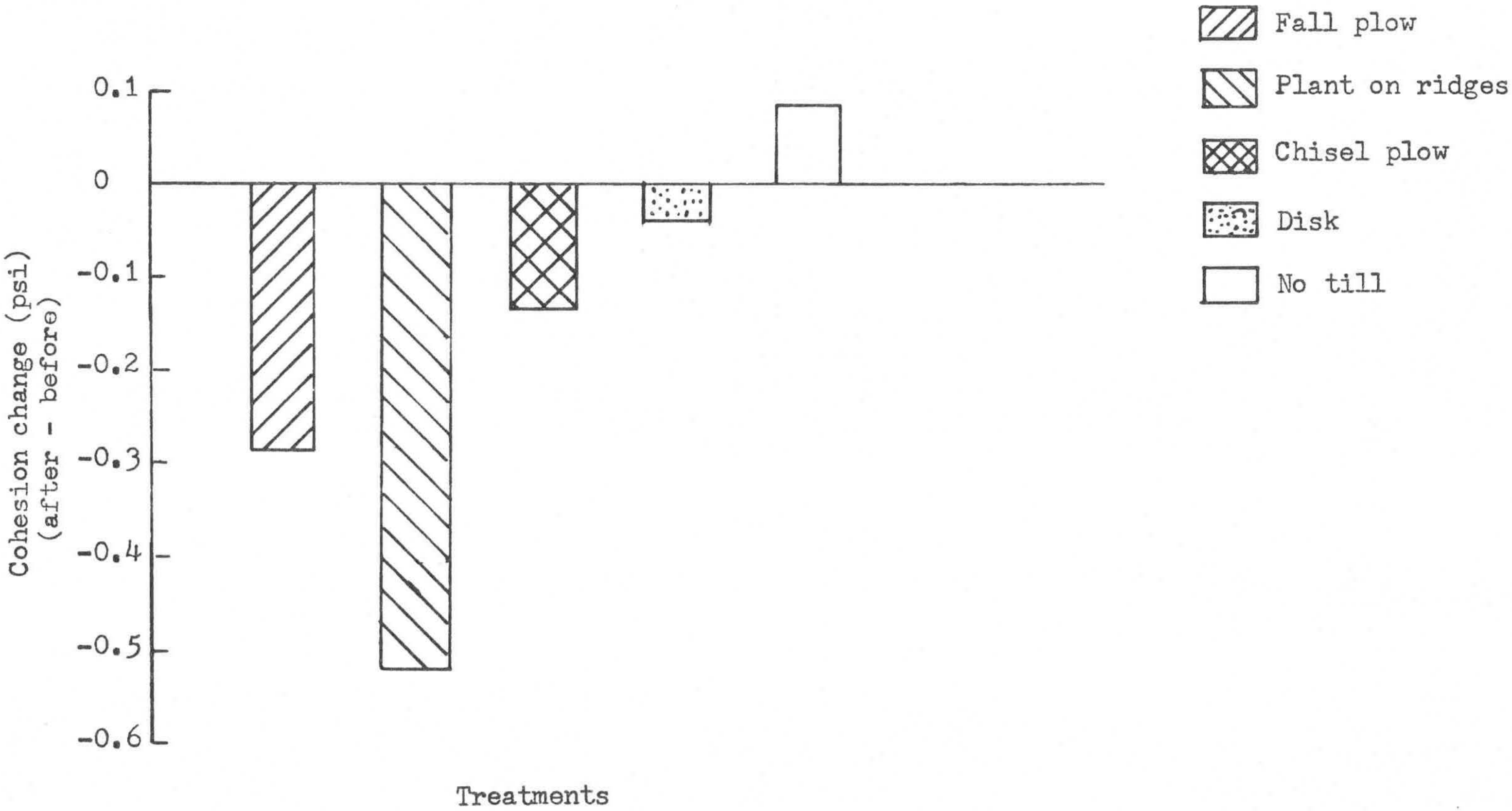

Figure 25. Cohesion changes as affected by cultivation operations in the row

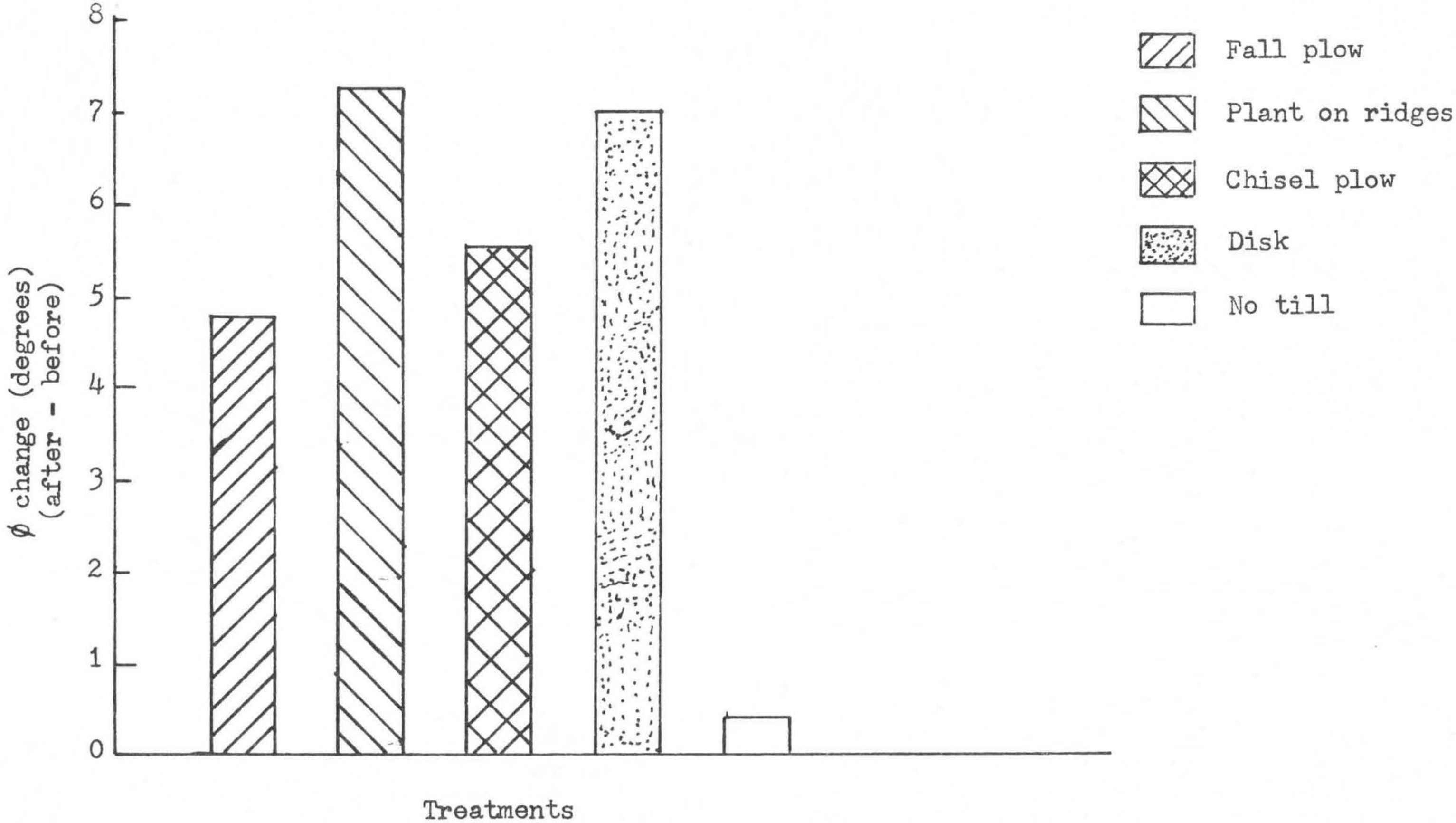

Figure 26. Angle of internal friction changes as affected by cultivation operations in the row

when the soil was thrown into the row area. The cohesive forces between oriented clay particles combined by moisture content and bulk density change could probably have caused the decrease in cohesion and the increase in angle of internal friction of the soil.

Bio-factor of Plant Measurements

Plant height

Table 24 shows corn plant height measurements for two dates during the growing season. The plant on ridges treatment resulted in shorter plants when compared to the rest of the treatments for the two date measurements. Average plant height of plow treatment was the tallest treatment in the experiment on both dates. Average plant height of no tillage treatment was approximately the same when compared to chisel plow and disk treatment on the first date, while for the second date, the no tillage treatment was shorter than disk and chisel plow treatment. A complete analysis of variance was run on the plant-height measurements. The calculated F values due to tillage systems (treatments), and date are 17.97 and 2884.51 respectively. The tabular F values for tillage systems and date at the 1% level are 4.77 and 8.10 respectively, meaning that differences in plant heights due to tillage systems and date are highly significant. The tillage systems x date interaction was not significant, as would be expected from the small differences among increments shown in Table 24. Analysis of variance table for height of plants are shown in Table C-1, Appendix C.

Two sets of four orthogonal comparisons were set up to examine tillage system effects. The first set of orthogonal comparisons involves

Table 24. Corn plant height[a] (cm) for two dates during the growing season

Tillage systems	Dates 1	Dates 2	Increment
Fall plow	116.23	196.54	80.31
Plant on ridges	96.16	180.94	84.78
Chisel plow	107.28	191.26	83.98
Disk	106.73	185.92	79.19
No till	105.71	183.39	78.68
Mean	106.42	187.71	81.29

[a]Each value reported in the table is an average of 50 individual measurements, 10 plants per plot on 5 plots.

the partitioning of the tillage systems sum of squares into four contrasts. The C_1 and C_3 contrasts were highly significant, while the C_2 and C_4 were not significant. The second set of orthogonal comparisons involves the partitioning of the tillage systems x date interaction sum of squares into four contrasts. The V_1, V_2, V_3, and V_4 were not significant. The statistical analysis table for the two sets of four orthogonal comparison are presented in Table 25.

Although no statistical difference was shown between any of the tillage systems for second date measurements, the means of the tillage systems indicate that fall plow and chisel plow plots grew taller corn plants as compared to that found for plant on ridges, disk and no till treatment.

Table 25. Analysis of variance mean squares for height of plants

Source[a]	DF	Mean squares[b]
Set 1		
Tillage system	4	424.59**
C_1	1	1085.02**
C_2	1	0.05
C_3	1	569.87**
C_4	1	43.41
Error	16	60.37
Set 2		
Treatment x date	4	21.50
V_1	1	2.97
V_2	1	37.47
V_3	1	17.07
V_4	1	28.50
Residual	20	28.64

[a]C_1, V_1 = Orthogonal comparison of the conventional system versus disk, plant on ridges, chisel plow and no tillage.

C_2, V_2 = Orthogonal comparison of no tillage versus chisel plow, plant on ridges and disk.

C_3, V_3 = Orthogonal comparison of plant on ridges versus chisel plow and disk.

C_4, V_4 = Orthogonal comparison of chisel plow versus disk.

[b]Probability level for F test of significance are indicated here.

**Significant at 1% level.

Conclusion   The fall plow and chisel plow treatments favored vegetative development of the plants.

Stand count

Corn stand counts were made for six dates during the growing cycle. Table 26 shows mean values of initial stand count and final stand count. Larger differences were observed between initial stand count for fall plow tillage system and the rest of the tillage systems. Similarly the same situation had better initial and final stand count than plant on ridges, chisel plow and disk tillage systems.

An analysis of variance for stand count was run on six dates during the growing season. Since for tillage systems, date and tillage systems x date interaction, the calculated F values are higher than tabular F values at 1% level, the differences in stand count are highly significant due to tillage systems, date and tillage systems x date interaction.

Table 26. Initial and final stand count for corn

	Stand count	
Tillage system	Initial (Plants/acre)	Final (Plants/acre)
Fall plow	26464	23650
Plant on ridges	19835	17760
Chisel plow	18159	17280
Disk	19648	17141
No till	19882	18982

A complete analysis of variance table for corn stand count is shown in Tables C-2, C-3, and C-4, Appendix C.

Two sets of four orthogonal comparison were set up to find out tillage system effects. The first set of orthogonal comparison correspond to initial stand count. The C_1 contrast was highly significant as reflected in the mean performance of fall plow tillage system (Table 26). The C_4 contrast was significant at the 5% level due to the variation for initial stand count between chisel plow and disk. The C_2 and C_3 contrast differences were not found to be significant as expected from the small variation for initial stand count. The second set of orthogonal comparison correspond to final stand count. The C_1 and C_2 contrast differences were highly significant as would be expected from the large fluctuations for final stand count among tillage systems shown in Table 26. The statistical analysis table for two sets of four orthogonal comparison are indicated in Tables 27 and 28.

In general, the highest stand count occurred with the fall plow treatment.

Corn yield

Table 29 shows the corn moisture at harvest and the corn yield of each tillage system. Highest and lowest average yields were produced in fall plow and disk treatments respectively. Highest and lowest corn moistures were obtained for fall plow and chisel plow treatments respectively. The yield of the plant on ridges, chisel plow and disk treatments

Table 27. Analysis of variance mean squares for initial stand count.

Source[a]	DF	Mean squares[b]
Tillage system	4	52701574.66**
C_1	1	200698222.24**
C_2	1	1673340.00
C_3	1	2890444.80
C_4	1	5544291.60*
Error	16	800122.93

[a]C_1 = Orthogonal comparison of the conventional system versus disk, plant on ridges, chisel plow and no tillage.

C_2 = Orthogonal comparison of no tillage versus chisel plow, plant on ridges and disk.

C_3 = Orthogonal comparison of plant on ridges versus chisel plow and disk.

C_4 = Orthogonal comparison of chisel plow versus disk.

[b]Probability level for F test of significance are indicated here.

*Significant at 5% level.

**Significant at 1% level.

were lower by 1.20, 4.12 and 12.64 bushels per acre, respectively, than the no till treatment. The corn moisture at harvest of chisel plow and disk treatments were approximately the same. The same situation is shown for corn moisture for plant on ridges and no till treatment.

Table 28. Analysis of variance mean squares for final stand count

Source[a]	DF	Mean squares[b]
Tillage system	4	36952997.35**
C_1	1	137292775.83**
C_2	1	9462893.06**
C_3	1	1007600.13
C_4	1	48720.40
Error	4	502129.13

[a]C_1 = Orthogonal comparison of the conventional system versus disk, plant on ridges, chisel plow and no tillage.

C_2 = Orthogonal comparison of no tillage versus chisel plow, plant on ridges and disk.

C_3 = Orthogonal comparison of plant on ridges versus chisel plow and disk.

C_4 = Orthogonal comparison of chisel plow versus disk.

[b]Probability level for F test of significance indicated here.

**Significant at 1% level.

An analysis of variance was calculated on corn moisture at harvest and yield data. The analysis of variance showed there were highly significant differences for yields but the tillage systems were not found to be significant for the variable, corn moisture, at harvest. The differences between treatments for the variable, yield, were primarily

Table 29. Corn moisture at harvest (%) and corn yield (bu per acre) of each treatment

Tillage system	Corn moisture (%)	Corn yield (bu per acre)
Fall plow	26.26	147.90
Plant on ridges	25.20	135.54
Chisel plow	24.38	132.62
Disk	24.64	124.10
No till	25.12	136.74

determined by stand. Complete analysis of variance table for corn moisture at harvest and yield is shown in Tables C-5, C-6, Appendix C.

A set of four orthogonal comparison was prepared to determine treatment effect. Table 30 shows the orthogonal comparisons and that C_2, C_3, and C_4 contrast differences were not significant. The C_1 contrast was highly significant as reflected by the highest yields produced for fall plow treatment and shown in Table 29.

Conclusion Fall plow treatment produced the highest yields in comparison to the other treatments studied in the experiment. These significant differences were primarily explained by stand.

Weed weight

Table 31 shows weed weight for all tillage systems. Highest and lowest average of weed weight were reached in no till and fall plow

Table 30. Analysis of variance mean squares for corn yield

Source[a]	DF	Mean squares[b]
Tillage system	4	366.85**
C_1	1	979.69**
C_2	1	134.40
C_3	1	171.84
C_4	1	181.47
Error	16	49.21

[a]C_1 = Orthogonal comparison of the conventional system versus disk, plant on ridges, chisel plow and no tillage.

C_2 = Orthogonal comparison of no tillage versus chisel plow, plant on ridges and disk.

C_3 = Orthogonal comparison of plant on ridges versus chisel plow and disk.

C_4 = Orthogonal comparison of chisel plow versus disk.

[b]Probability level for F test of significance are indicated here.

**Significant at 1% level.

treatments respectively. The weed weight of the plant on ridges and disk treatments were higher than chisel plow treatment. This demonstrates the ability of conventional system (fall plow) for the control of annual weeds and the effect of poor weed control on plant on ridges, disk and no till system.

Table 31. Mean weed weight for tillage systems

Tillage system	Weed weight (lb DM per acre)
Fall plow	89.01
Plant on ridges	3266.17
Chisel plow	1052.66
Disk	1740.91
No till	3678.13

The orthogonal comparison showed that the conventional system (fall plow) versus disk, plant on ridges, chisel plow and no tillage was significant. The significance of this contrast was due to the low weed weight in fall plow treatment. The remaining of the contrasts were significant, as would be expected from the appreciable fluctuations between tillage systems shown in Table 31. An analysis of variance table for weed weight is given in Table C-7, Appendix C. Values of corn yield, corn moisture and weed weight are given in Table C-8, Appendix C.

Conclusion The results show conclusively that the degree of weed weight among tillage systems was highly significant. High weed infestation was reached in no tillage, plant on ridges and disk treatments. The conventional system (fall plow) and chisel plow treatment gave the lowest weed infestation.

A correlation matrix was calculated for four parameters in selected tests. Coefficient of correlation is a measure of the degree to which two variables vary together.

In Table 32 the correlation of stand, weed control and yield observations are shown. The table indicates that the test of significance of the correlation coefficients of the parameters studied were not significant at 0.01 and 0.05 levels.

Yield data were evaluated by analysis of variance (Table 33) and included terms for replication variables to account for fertility differences, final stand count, weed weight, height of plant and cone index at the three depths. The three types of analysis were fitted to the corn yield data: an analysis of regression for replications, an analysis of covariance for final stand count, weed weight, height of plants, and the principal components analysis for cone index.

The analysis of variance for yield as the dependent variable shown in Table 33 shows that replications, weed weight, height of plants, and cone index at the three depths are not significant. It reveals that these parameters did not affect corn yield. The final stand count was found to be highly significant.

Conclusion The corn yields were considerably improved by final stand count with an average stand of 18,963 plants per acre.

A complete analysis of variance for dependent variable yield are given in Tables C-9, C-10, Appendix C.

Table 32. Correlation of stand, weed control, and yield observations

	Stand (plants/A)		Weed control	Yield
	Initial	Final	(lbs dry matter/A)	(bu/A)
Initial stand (Plants/A)	1.000			
Final stand (Plants/A)	0.368 ns[a]	1.000		
Weed control (lbs dry matter/A)	0.440 ns	0.340 ns	1.000	
Yield (bu/A)	0.164 ns	-0.170 ns	-0.384 ns	1.000

[a]ns = No significant difference detected at 0.01 and 0.05 level.

Table 33. Analysis of variance for corn yields in terms of replications, stand count, weed weight, height of plants and cone index change (after - before)

Source[a]	DF	Mean square[b]
Replications	4	301.942
Stand	1	598.067**
Weed	1	150.527
Height	1	0.805
CID_1	1	43.601
CID_2	1	25.251
CID_3	1	35.916

[a]CID_1 = Cone index change at 0 to 7 inches depth, CID_2 = Cone index change at 14 inches depth, CID_3 = Cone index at 21 inches depth.

[b]Probability levels for F tests of significance are indicated here.

**Significant at 1% level.

SUMMARY AND CONCLUSIONS

It is generally accepted that tillage operations are essential to the maintenance of good physical conditions of the soil and beneficial to crop yields. However, the exact nature of these tillage operation effects and how these changes are brought about are, in many instances, questions yet to be answered.

The general purpose of this study was to determine the effects of corn tillage systems on physical properties of the soil and bio-factors of plants. The specific purpose was to determine the influence of corn tillage systems on the bulk density and moisture content; to determine the influence of corn tillage systems on the cone index of the soil; to determine the influence of corn tillage systems on cohesion and angle of internal friction of the soil; and to determine the effects of corn tillage operations on the bio-factors of plants--such as height of plants, stand count, weed control, corn moisture at harvest and corn yields.

The tillage systems used in this study were fall plow, plant on ridges, chisel plow, disk and no till. Measurements were made to determine the influence of the corn tillage operations on bulk density, soil moisture, cone index, cohesion and angle of internal friction. Bulk density and moisture content, both on oven-dry weight basis, were determined on undisturbed soil cores, 3 inches in diameter and 3 inches long. The soil sheargraph was used for measuring the cohesion and angle of internal friction of the soil. Penetrometer readings were taken with a cone penetrometer. Bio-factor of plants measurements were made to determine the effect of the corn tillage operations on plant height, stand count, weed control, corn moisture at harvest and corn yields.

On the basis of the results of this study, it is concluded that

1. The tillage systems did not materially influence the moisture content of the soil.
2. The tillage systems had no significant effect on the cone index of the soil.
3. The tillage systems had no significant effect on the angle of internal friction of the soil.
4. The tillage system had no significant effect on values of cohesion of the soil.
5. The cultivation operations had no effect on bulk density of the soil.
6. The fall plow and chisel plow treatments favored vegetative development of the plants.
7. The highest stand count occurred with the fall plow treatment.
8. Fall plow treatment produced the highest yields in comparison to the other treatments and yield difference could be accounted for by differences in stands.
9. The conventional system (fall plow) and chisel plow gave the lowest weed infestation.
10. The corn yields were considerably improved by final stand count with an average stand of 18,963 plants per acre.
11. Weed weight, height of plants, and cone index did not affect corn yields.
12. Final stand count revealed a highly significant effect on corn yield.

LITERATURE CITED

1. Agricultural Engineers Yearbook. Soil Cone Penetrometer. St. Joseph, Michigan, American Society of Agricultural Engineers. 1971.

2. Aldabagh, A. S. Effect of tile drainage on agricultural equipment. Unpublished Ph.D. Thesis. Ames, Iowa, Library, Iowa State University of Science and Technology. 1971.

3. Alderfer, R. B., and Merkle, F. G. Structural stability and permeability of native forest soils compared with cultivated areas of the same soil type. Soil Sci. Soc. Am. Proc. 6:98-103. 1941.

4. Allmaras, R. R. Soil water storage as affected by infiltration and evaporation in relation to tillage-induced soil structure. Conf. Proc. "Tillage for Greater Crop Production", Detroit, Michigan. ASAE Publication Proc. 168:37-43. December, 1967.

5. Allmaras, R. R., Burwell, R. E., and Holt, R. F. Plow-layer porosity and surface roughness from tillage as affected by initial porosity and soil moisture at tillage time. Soil Sci. Soc. Amer. Proc. 31:550-556. 1967.

6. Allmaras, R. R., Burwell, R. E., Vorhees, W. B. and Larson, W. E. Aggregate size distribution in the row zone of tillage experiments. Soil Sci. Soc. Am. Proc. 29:645-650. 1965.

7. Arndt, W. The impedance of soil seeds and the forces of emerging seedling. Australian Journal of Soil Research 3:55-68. 1965.

8. __________. The nature of the mechanical impedance to seedlings by soil surface seals. Australian Journal of Soil Research 3:45-54. 1965.

9. Barley, K. P., and Greacen, E. L. Mechanical resistance as a soil factor influencing the growth of roots and underground shoots. Advances in Agronomy 19:1-40. 1967.

10. Bateman, H. P. Effects of basic tillage method and soil compaction on corn production. Ill. Agr. Exp. Sta. Bul. 645. 1959.

11. Baver, L. D. Soil physics, 3rd ed. New York, N.Y., John Wiley and Sons. 1956.

12. Bear, E. B. Soil management. 1st ed. New York, N.Y., John Wiley and Sons. 1924.

13. Beer, C. E., Shrader, W. D., and Schwanke, R. K. Interrelationships of plant populations, soil moisture and soil fertility in

determining corn yield on Colo clay loam at Ames, Iowa. Iowa Agr. and Home Econ. Exp. Sta. Res. Bul. 556. 1967.

14. Black, C. A. Soil-plant relationships. 1st ed. New York, N.Y., John Wiley and Sons, Inc. 1957.

15. Bowen, H. D. Measurement of edaphic factors for determining planter specifications. American Society of Agricultural Engineers Transactions 9:725-735. 1966.

16. Bradford, J. M. Effect of soil overburden pressure on penetration of fine metal probes. Unpublished Ph.D. Thesis. Ames, Iowa, Library, Iowa State University of Science and Technology. 1968.

17. Browning, G. M., and Norton, R. A. Tillage practices on selected soils in Iowa. Soil Sci. Soc. Amer. Proc. 10:461-468. 1946.

18. Buchele, W. F. A power sampler of undisturbed soils. American Society of Agricultural Engineers Transactions 4:185-187, 191. 1961.

19. Buchele, W. F., Collins, E. V., and Lovely, W. G. Ridge farming for soil and water control. Agric. Eng. 36:324-329, 331. 1955.

20. Carmer, S. G. and Jackobs, J. A. An exponential model for predicting optimum plant density and maximum corn yield. Agron. J. 57: 241-244. 1965.

21. Cohron, G. T. Cohron sheargraph for shearing strength measurements. The Journal of Environmental Science 6:17-20, December, 1963.

22. __________. Soil sheargraph. Agricultural Engineering 44:(10) 554-556. 1963.

23. Currence, H. D. Development of a method for measuring and describing soil surface roughness. Unpublished Ph.D. Thesis. Ames, Iowa, Library, Iowa State University of Science and Technology. 1969.

24. Diebold, C. H. Effect of tillage upon intake rates and run off and soil losses of dry farm land soils. Soil Soc. Am. Proc. 18:88-91. 1954.

25. Donahue, R. L., Shickluna, J. C., and Robertson, L. S. Soils: an introduction to soils and plant growth. 3rd ed. Englewood Cliffs, New Jersey, Prentice Hall, Inc. 1971.

26. Dungan, G. H., Lang, A. L., and Pendleton, J. W. Corn plant population in relation to soil productivity. Advances in Agron. 10: 435-473. 1958.

27. Dunlap, W. H., Vanden Berg, G. E., and Hendrick, J. G. Comparison of Soil Shear Values Obtained with Devices of Different Geometrical Shapes. ASAE Trans. 9:(6)896-900. 1966.

28. Erbach, D. C., Wilkins, D. E., and Lovely, G. W. An evaluation of chemical and mechanical weed control for soybeans grown with no-plow tillage systems. NCWCC Proc. 24:74-75. 1969.

29. Erbach, D. C., Wilkins, D. E., and Lovely, G. W. Relationships between furrow opener, corn plant spacing, and yield. Agron. J. 64:702-704. 1972.

30. Furr, J. R., and Reeve, J. O. The range of soil-moisture percentages through which plants undergo permanent wilting in some soils from semi-arid irrigated areas. Journal of Agricultural Research 71:149-170. 1945.

31. Gardner, W. R. Water content. In Black, C. A., ed. Physical and mineralogical properties, including statistics of measurement and sampling. Pp. 82-125. Madison, Wisconsin, American Society of Agronomy. 1965.

32. Gill, W. R., and Miller, R. D. A method for study of the influence of mechanical impedance and aeration on the growth of seedling roots. Soil Sci. Soc. Am. Proc. 20:154-157. 1956.

33. Gill, W. R., and Vanden Berg, G. E. Soil dynamics in tillage and traction. United States Department of Agriculture Research Service Agriculture Handbook No. 316. 1968.

34. Holt, R. F., Timmons, D. R., Voorhees, W. B., and Van Doren, C. A. Importance of stored soil moisture to the growth of corn in the dry to moist sub humid climatic zone. Agron. J. 56:82-85. 1964.

35. James, A. L. Some influences of soil atmosphere on germination of annual weeds. Unpublished Ph.D. Thesis. Ames, Iowa, Library, Iowa State University of Science and Technology. 1968.

36. Jensen, C. R. Soil compaction, soil moisture, and soybean growth. Unpublished M.S. Thesis. Ames, Iowa, Library, Iowa State University of Science and Technology. 1959.

37. Johnson, W. H., and Buchele, W. F. Influence of soil granule size and compaction on rate of soil drying and emergence of corn. Am. Soc. Agr. Eng. Trans. 4:170-174. 1961.

38. Kirkham, D. Use of nuclear energy in water studies for increasing agricultural productivity. Ames, Iowa, Iowa State Water Resources Research Institute, Iowa State University. 1968.

39. Kirkham, D., and Powers, W. L. Advanced soil physics. 1st ed. New York, N.Y., John Wiley and Sons, Inc. 1972.

40. Kohnke, H. Soil physics. 1st ed. New York, N.Y., McGraw-Hill Book Company. 1968.

41. Kollman, G. E. Influence of soil compaction on weed seedling emergence. Unpublished Ph.D. Thesis. Ames, Iowa, Library, Iowa State University of Science and Technology. 1968.

42. Kuipers, H. The objectives of soil tillage. Neth. J. Agric. Sci. 11:91-96. 1963.

43. __________. A relief meter for soil cultivation studies. Neth. J. Agric. Sci. 5:225-262. 1957.

44. Larson, W. E. Important soil parameters for evaluating tillage practices in the U.S. Neth. J. Agric. Sci. 11:100-109. 1963.

45. __________. Potential and need for soil tillage research. Conf. Proc. "Tillage for Greater Crop Croduction", Detroit, Michigan. ASAE Publication Proc. 168:3-9. December, 1967.

46. __________. Soil parameters for evaluating tillage needs and operations. Soil Sci. Am. Proc. 28:118-122. 1964.

47. Larson, W. E., and Blake, G. R. Seedbed and tillage requirements. In Pierre, W. P., Aldrich, S. R., and Martin, W. P., eds. Advances in corn production: Principles and practices. Pp. 28-52. Ames, Iowa, The Iowa State University Press. 1966.

48. Lemos, P., and Lutz, J. F. Soil crusting and some factors affecting it. Soil Sci. Soc. Proc. 21:485-491. 1957.

49. Lovely, W. G., Weber, C. R., and Staniforth, D. W. Effectiveness of the rotary hoe for weed control in soybeans. Agron. J. 50:621-625. 1958.

50. Luttrell, D. H. The effect of tillage operations on bulk density and other physical properties of the soil. Unpublished Ph.D. Thesis. Ames, Iowa, Library, Iowa State University of Science and Technology. 1963.

51. McClelland, J. H. Instrument for measuring soil condition. Ag. Engr. 37:480-481. 1956.

52. McVickar, M. H., and Shear, G. M. Variation in response of different varieties and hybrids of field corn to planting rate. Amer. Soc. Agron. J. 10:933-935. 1946.

53. Moldenhauer, W. C., and Wischmeier, W. H. Soil and water losses and infiltration rates in Ida silt loam as influenced by cropping systems, tillage practices, and rainfall characteristics. Soil Sci. Soc. Amer. Proc. 24:409-414. 1960.

54. Moldenhauer, W. C., Lovely, W. G., Swanson, N. P., and Currence, H. D. Effect of row grades and tillage systems on soil and water losses. J. Soil and Water Cons. 26:193-195. 1971.

55. Morton, C. T., and Buchele, W. F. Emergence energy of plant seedlings. Agricultural Engineering 41:428-431, 453-455. 1960.

56. Muhr, G. R., and Rost, C. O. The effect of population and fertility on yields of sweet corn and field corn. Agron. J. 43:315-319. 1951.

57. Page, J. B., Willard, C. J., and McCuen, G. W. Progress report on tillage methods in preparing land for corn. Soil Sci. Soc. Amer. Proc. 11:77-80. 1947.

58. Panwar, J. S., and Siemens, J. C. Soil shear strength and energy for failure related to density and moisture. American Society of Agricultural Engineers Paper No. 70-140. 1970.

59. Partridge, M. Early Agricultural Machinery. 1st ed. New York, N.Y., Frederick A. Praeger, Publishers, 1969.

60. Phillips, R. E. Soil compaction and corn growth. Unpublished Ph.D. Thesis. Ames, Iowa, Library, Iowa State University of Science and Technology. 1959.

61. Richard, L. A., and Wadleigh, C. H. Soil water and plant growth. In Shaw, B. T., ed. Soil physical condition and plant growth. Am. Soc. Agron. Monograph Vol. 2. Pp. 73-251. New York, N.Y., Academic Press, Inc. 1952.

62. Rossman, E. L., and Cook, R. L. Seed preparation and date rate and pattern of planting. In Pierre, W. P., Aldrich, S. R., and Martin, W. P., eds. Advances in corn production: Principles and practices. Pp. 54-93. Ames, Iowa, The Iowa State University Press. 1966.

63. Schafer, R. L., and Lovely, W. G. A recording soil surface profile meter. Agricultural Engineering 48:280-282. 1967.

64. Schwab, G. O., Frevert, R. K., Administer, T. W., and Barnes, K. K. Soil and water conservation engineering. 2nd ed. New York, N.Y., John Wiley and Sons, Inc. 1966.

65. Schwanke, R. K. The interrelationships of plant population, soil moisture, and soil fertility in determining corn yields on Colo clay loam. Unpublished M.S. Thesis. Ames, Iowa, Library, Iowa State University of Science and Technology. 1963.

66. Sedgley, R. H., and Barley, K. P. The effect of a small axial pressure on the growth of the epicotyl of Viciafaba Variety Minor Beck. Australian Journal of Biological Science 16:19-27. 1963.

67. Shaw, R. H., Nielsen, D. R., and Runkles, J. R. Evaluation of some soil moisture characteristics of Iowa Soils. Iowa Agr. and Home Econ. Exp. Sta. Res. Bul. 465. 1959.

68. Smith, E. M., Taylor, T. H., and Smith, S. W. Soil moisture measurements using gamma transmission techniques. ASAE Trans. 10:(2)205-208. 1967.

69. Soane, B. D. A gamma-ray transmission method for the measurement of soil density in field tillage studies. J. Agric. Engng. Res. 13:(4)340-349. 1968.

70. Stickler, F. C. Row width and plant population studies in corn. Agron. J. 56:438-441. 1964.

71. Stong, J. V., and Buchele, W. F. Effect of soil parameters on strength of tillable soils. American Society of Agricultural Engineers Paper No. 62-132. 1962.

72. Thompson, L. M. Weather and technology in the production of corn and soybeans. CAED [The Center for Agricultural and Economic Development, Iowa State University, Ames, Iowa.] 1963.

73. Timmons, D. R., Holt, R. F., and Moraghan, J. F. Effect of corn population on yield, evapotranspiration, and water-use efficiency in the Northwest Corn Belt. Agron. J. 58:429-432. 1966.

74. United States Department of Agriculture. Agricultural Statistics. Washington, D.C., U.S. Government Printing Office. 1971.

75. Van Doren, D. M. Influence of plowing, disking; cultivation, previous crop and surface residues on corn yield. Soil Sci. Soc. Amer. Proc. 29:595-597. 1965.

76. Van Doren, D. M., Jr., and Ryder, G. J. Factors affecting use of minimum tillage for corn. Agron. J. 54:447-450. 1968.

77. Wald, A. J. Evaluation of rotary tillage systems for corn production. Unpublished M.S. Thesis. Ames, Iowa, Library, Iowa State University of Science and Technology. 1968.

78. Wanjura, D. F., Hudspeth, E. B., and Kirk, I. W. Effects of compaction on cotton emergence. Texas Agricultural Experiment Station Miscellaneous Publication 800. 1966.

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APPENDIX A

Table A-1. Analysis of variance for moisture content before tillage-planting operations

Source[a]	Degrees of freedom	Mean square
REP	2	17.782
T. SYSTEM	4	28.802
ERROR (a)	8	31.153
POS	1	220.171*
T. SYSTEM x POS	4	3.070
ERROR (b)	10	34.266
DEP	4	48.935**
T. SYSTEM x DEP	16	4.872*
POS x DEP	4	16.021**
T. SYSTEM x POS x DEP	16	4.767
ERROR (c)	80	2.736
CORRECTED TOTAL	149	

[a]REP = Replication, T. SYSTEM = Tillage system, POS = Position, DEP = Depth.

*Significant at 5% level.

**Significant at 1% level.

Table A-2. Analysis of variance for moisture content after tillage-planting operations

Source[a]	Degrees of freedom	Mean square
REP	2	26.381
T. SYSTEM	4	16.493
ERROR (a)	8	16.579
POS	1	3.213
T. SYSTEM x POS	4	0.822
ERROR (b)	10	3.344
DEP	4	214.649**
T. SYSTEM x DEP	16	4.366
POS X DEP	4	4.411
T. SYSTEM x POS x DEP	16	1.165
ERROR (c)	80	3.526
CORRECTED TOTAL	149	

[a]REP = Replication, T. SYSTEM = Tillage systems, POS = Position, DEP = Depth.

**Significant at 1% level.

Table A-3. Analysis of variance for moisture content change (after - before) tillage planting operations

Source[a]	Degrees of freedom	Mean square
REP	2	40.670
T. SYSTEM	4	148.536
ERROR (a)	8	147.539
POS	1	553.167*
T. SYSTEM x POS	4	3.657
ERROR (b)	10	59.103
DEP	4	130.210**
T. SYSTEM x DEP	16	22.386
POS x DEP	4	49.425
T. SYSTEM x POS x DEP	16	12.699
ERROR (c)	80	14.229
RESIDUAL	150	0.535
CORRECTED TOTAL	299	

[a]REP = Replication, T. SYSTEM = Tillage system, POS = Position, DEP = Depth.

*Significant at 5% level.

**Significant at 1% level.

Table A-4. Analysis of variance of the depth for linear and quadratic effect in change (after - before) tillage-planting operations

Source[a]	Degrees of freedom	Mean square
DL	1	430.547**
DQ	1	47.447
LF	2	21.424

[a]DL = Depth linear effect, DQ = Depth quadratic effect, LF = Lack of fit.

**Significant at 1% level.

Table A-5. Analysis of variance for cone index before tillage-planting operations

Source[a]	Degrees of freedom	Mean square
REP	4	7931.136**
T. SYSTEM	4	2866.502*
ERROR (a)	16	820.587
POS	1	8.173
T. SYSTEM x POS	4	122.214
ERROR (b)	20	265.088
DEP	2	3969.581**
T. SYSTEM x DEP	8	1093.439**
POS x DEP	2	873.865**
T. SYSTEM x POS x DEP	8	232.978
ERROR (c)	80	164.281
CORRECTED TOTAL	149	

[a]REP = Replication, T. SYSTEM = Tillage system, POS = Position, DEP = Depth.

*Significant at 5% level.

**Significant at 1% level.

Table A-6. Analysis of variance for cone index after tillage-planting operations

Source[a]	Degrees of freedom	Mean square
REP	4	1753.319*
T. SYSTEM	4	433.480
ERROR	16	583.725
POS	1	79.270
T. SYSTEM x POS	4	192.660
ERROR (b)	20	155.254
DEP	2	3363.837**
T. SYSTEM x DEP	8	111.902
POS x DEP	2	300.186
T. SYSTEM x POS x DEP	8	229.230
ERROR (c)	80	114.011
CORRECTED TOTAL	149	276.642

[a]REP = Replication, T. SYSTEM = Tillage system, POS = Position, DEP = Depth.

*Significant at 5% level.

**Significant at 1% level.

Table A-7. Analysis of variance for depth of cone index in tillage-planting operations

Source[a]	Degrees of freedom	Mean squares[b]		
		Before	After	Change (after - before)
DEP	2	3969.581**	3363.837**	59.020
DL	1	7750.198**	6631.263**	87.189
DQ	1	188.964	96.410	30.851
ERROR	80	164.281	114.011	543.174

[a]DEP = Depth, DL = Depth linear effect, DQ = Depth quadratic effect.

[b]Probability levels for F tests of significance are indicated here.

**Significant at 1% level.

Table A-8. Analysis of variance for cone index change (after - before) tillage-planting operations

Source[a]	Degrees of freedom	Mean square
REP	4	30337.451**
T. SYSTEM	4	2262.229
ERROR (a)	16	1325.722
POS	1	73.071
T. SYSTEM x POS	4	641.559
ERROR (b)	20	813.323
DEP	2	59.020
T. SYSTEM x DEP	8	1474.169
POS x DEP	2	301.134
T. SYSTEM x POS x DEP	8	870.673
ERROR (c)	80	543.174
RESIDUAL	150	508.887
CORRECTED TOTAL	299	1036.060

[a]REP = Replication, T. SYSTEM = Tillage system, POS = Position, DEP = Depth.

*Significant at 5% level.

**Significant at 1% level.

Table A-9. Analysis of variance for cohesion before tillage-planting operations

Source[a]	Degrees of freedom	Mean square
REP	3	0.037
T. SYSTEM	4	0.025
ERROR (a)	12	0.033
POS	1	0.031
T. SYSTEM x POS	4	0.063
ERROR (b)	15	0.026
CORRECTED TOTAL	39	

[a]REP = Replication, T. SYSTEM = Tillage system, POS = Position.

Table A-10. Analysis of variance for angle of internal friction before tillage-planting operations

Source[a]	Degrees of Freedom	Mean square
REP	3	24.664
T. SYSTEM	4	17.584
ERROR (a)	12	18.443
POS	1	2166.489**
T. SYSTEM x POS	4	29.851
ERROR (b)	15	12.264
CORRECTED TOTAL	39	

[a]REP = Replication, T. SYSTEM = Tillage system, POS = Position.

**Significant at 1% level.

Table A-11. Analysis of variance for cohesion after tillage-planting operations

Source[a]	Degrees of freedom	Mean square
REP	3	0.072
T. SYSTEM	4	0.191
ERROR (a)	12	0.160
POS	1	0.073
T. SYSTEM x POS	4	0.267*
ERROR (b)	15	0.085
CORRECTED TOTAL	39	

[a]REP = Replication, T. SYSTEM = Tillage system, POS = Position.

*Significant at 5% level.

Table A-12. Analysis of variance for angle of internal friction after tillage-planting operations

Source[a]	Degrees of freedom	Mean square
REP	3	141.577
T. SYSTEM	4	44.949
ERROR (a)	12	60.147
POS	1	0.183
T. SYSTEM x POS	4	8.666
ERROR (b)	15	13.102
CORRECTED TOTAL	39	

[a]REP = Replication, T. SYSTEM = Tillage system, POS = Position.

Table A-13. Analysis of variance for cohesion change (after - before) tillage-planting operations

Source[a]	Degrees of freedom	Mean square
REP	3	0.013
T. SYSTEM	4	0.247
ERROR (a)	12	0.128
POS	1	0.201
T. SYSTEM x POS	4	0.218
ERROR (b)	15	0.058
CORRECTED TOTAL	39	

[a]REP = Replication, T. SYSTEM = Tillage system, POS = Position.

*Significant at 5% level.

Table A-14. Analysis of variance for angle of internal friction change (after - before) tillage-planting operations

Source[a]	Degrees of freedom	Mean square
REP	3	52.379
T. SYSTEM	4	74.110
ERROR (a)	12	70.885
POS	1	2206.561**
T. SYSTEM x POS	4	8.579
ERROR (b)	15	20.316
CORRECTED TOTAL	39	

[a]REP = Replication, T. SYSTEM = Tillage system, POS = Position.

**Significant at 1% level.

Table A-15. Analysis of variance for variable moisture content and bulk density change (after - before) tillage-planting operations in soil sheargraph

Source[a]	Degrees of freedom	Mean squares[b] Moisture content	Bulk density
REP	3	36.212	0.033
T. SYSTEM	4	1.512	0.061**
ERROR (a)	12	8.424	0.007
POS	1	22.290	4.029**
T. SYSTEM x POS	4	6.076	0.051*
ERROR (b)	15	5.756	0.013
CORRECTED TOTAL	39	8.941	

[a]REP = Replication, T. SYSTEM = Tillage system, POS = Position.

[b]Probability level for F tests of significance are indicated here.

*Significant at 5% level.

**Significant at 1% level.

APPENDIX B

Table B-1. Analysis of variance for variable bulk density before cultivation operations

Source[a]	Degrees of freedom	Mean square
REP	4	0.673**
T. SYSTEM	4	0.048
ERROR (a)	16	0.125
POS	1	0.712
T. SYSTEM x POS	4	0.340
ERROR (b)	20	0.182
DEP	4	0.956*
T. SYSTEM x DEP	16	0.147
POS x DEP	4	0.124
T. SYSTEM x POS x DEP	16	0.151
ERROR (c)	158	0.157
RESIDUAL	248	0.142
CORRECTED TOTAL	495	0.161

[a]REP = Replication, T. SYSTEM = Tillage system, POS = Position, DEP = Depth.

*Significant at 5% level.

**Significant at 1% level.

Table B-2. Analysis of variance for variable bulk density after cultivation operations

Source[a]	Degrees of freedom	Mean square
REP	4	0.063
T. SYSTEM	4	0.030
ERROR (a)	16	0.063
POS	1	1.085**
T. SYSTEM x POS	4	0.006
ERROR (b)	20	0.051
DEP	4	0.889**
T. SYSTEM x DEP	16	0.033
POS x DEP	4	0.204
T. SYSTEM x POS x DEP	16	0.033
ERROR (c)	160	0.026
RESIDUAL	248	0.001
CORRECTED TOTAL	497	.

[a]REP = Replication, T. SYSTEM = Tillage system, POS = Position, DEP = Depth.

**Significant at 1% level.

Table B-3. Analysis of variance of the bulk density depth for linear, quadratic and lack of fit in cultivation operations

Source[a]	Degrees of freedom	Mean squares[b]		
		Before	After	Change (after - before)
DEP	4	0.956*	0.888**	0.072
DL	1	2.713**	3.019**	0.001
DQ	1	0.666*	0.510**	0.016
LF	2	0.224	0.015	0.135
ERROR		0.157(158)[c]	0.026(160)	0.168(158)

[a]DEP = Depth, DL = Depth linear effect, DQ = Depth quadratic effect, LF = Lack of fit.

[b]Probability levels for F tests of significance are indicated here.

[c]() Degrees of freedom.

*Significant at 5% level.

**Significant at 1% level.

Table B-4. Analysis of variance for variable bulk density change (after-before) cultivation operations

Source[a]	Degrees of freedom	Mean square
REP	4	0.613*
T. SYSTEM	4	0.082
ERROR (a)	16	0.199
POS	1	0.030
T. SYSTEM x POS	4	0.310
ERROR (b)	20	0.170
DEP	4	0.072
T. SYSTEM x DEP	16	0.165
POS x DEP	4	0.420*
T. SYSTEM x POS x DEP	16	0.188
ERROR (c)	158	0.168
RESIDUAL	246	0.144
CORRECTED TOTAL	493	

[a]REP = Replication, T. SYSTEM = Tillage system, POS = Position, DEP = Depth.

*Significant at 5% level.

Table B-5. Analysis of variance for variable moisture content before cultivation operations

Source[a]	Degrees of freedom	Mean square
REP	4	518.537**
T. SYSTEM	4	79.231
ERROR (a)	16	100.656
POS	1	13.394
T. SYSTEM x POS	4	23.963
ERROR (b)	20	19.889
DEP	4	70.968**
T. SYSTEM x DEP	16	18.023
POS x DEP	4	70.931**
T. SYSTEM x POS x DEP	16	8.203
ERROR (c)	153	12.852
RESIDUAL	243	0.174
CORRECTED TOTAL	485	15.473

[a]REP = Replication, T. SYSTEM = Tillage system, POS = Position, DEP = Depth.

**Significant at 1% level.

Table B-6. Analysis of variance for variable moisture content after cultivation operations

Source[a]	Degrees of freedom	Mean square
REP	4	366.631*
T. SYSTEM	4	47.819
ERROR (a)	16	88.728
POS	1	167.353*
T. SYSTEM x POS	4	19.286
ERROR (b)	20	15.259
DEP	4	165.975**
T. SYSTEM x DEP	16	15.164
POS x DEP	4	21.254
T. SYSTEM x POS x DEP	16	12.164
ERROR (c)	160	12.083
RESIDUAL	248	1.180
CORRECTED TOTAL	497	14.163

[a]REP = Replication, T. SYSTEM = Tillage system, POS = Position, DEP = Depth.

*Significant at 5% level.

**Significant at 1% level.

Table B-7. Analysis of variance for linear, quadratic and lack of fit for main effect depth for cultivation operations

Source[a]	Degrees of freedom	Mean squares[b]		
		Before	After	Change (after - before)
DEP	4	70.968**	165.975**	89.113**
DL	1	163.489**	200.262**	0.259
DQ	1	0.416	297.986**	319.020**
LF	2	59.984**	82.825**	18.588
ERROR		12.852(153)	12.083(160)	20.707(153)

[a]DEP = Depth, DL = Depth linear effect, DQ = Depth quadratic effect, LF = Lack of fit.

[b]Probability levels for F tests of significance are indicated here.

[c]() Degrees of freedom.

**Significant at 1% level.

Table B-8. Analysis of variance for variable moisture content change (after - before) cultivation operations

Source[a]	Degrees of freedom	Mean square
REP	4	95.488
T. SYSTEM	4	23.673
ERROR (a)	16	52.024
POS	1	319.955*
T. SYSTEM x POS	4	47.036
ERROR (b)	20	42.173
DEP	4	89.113**
T. SYSTEM x DEP	16	12.388
POS x DEP	4	60.456*
T. SYSTEM x POS x DEP	16	23.518
ERROR (c)	153	20.707
RESIDUAL	241	1.380
CORRECTED TOTAL	483	15.184

[a]REP = Replication, T. SYSTEM = Tillage system, POS = Position, DEP = Depth.

*Significant at 5% level.

**Significant at 1% level.

Table B-9. Analysis of variance for variable cone index before cultivation operations

Source[a]	Degrees of freedom	Mean square
REP	4	5804.837**
T. SYSTEM	4	2666.019*
ERROR (a)	16	359.871
POS	1	1695.796*
T. SYSTEM x POS	4	206.731
ERROR (b)	20	216.731
DEP	2	79653.564**
T. SYSTEM x DEP	8	744.514
POS x DEP	2	2745.884**
T. SYSTEM x POS x DEP	8	194.682
ERROR (c)	80	192.489
RESIDUAL	150	102.865
CORRECTED TOTAL	299	834.912

[a]REP = Replication, T. SYSTEM = Tillage system, POS = Position, DEP = Depth.

*Significant at 5% level.

**Significant at 1% level.

Table B-10. Analysis of variance for cone index after cultivation operations

Source[a]	Degrees of freedom	Mean square
REP	4	10853.859**
T. SYSTEM	4	273.871
ERROR (a)	16	602.453
POS	1	1597.195
T. SYSTEM x POS	4	1133.071
ERROR (b)	20	458.356
DEP	2	68138.287**
T. SYSTEM x DEP	8	1765.991**
POS x DEP	2	201.499
T. SYSTEM x POS x DEP	8	103.251
ERROR (c)	80	279.526
RESIDUAL	150	210.514
CORRECTED TOTAL	299	919.798

[a]REP = Replication, T. SYSTEM = Tillage system, POS = Position, DEP = Depth.

**Significant at 1% level.

Table B-11. Analysis of variance for linear and quadratic effects for main factor depth in cultivation operations

Source[a]	Degrees of freedom	Mean squares[b] Before	After	Change (after - before)
DEP	2	79653.564**	68138.287**	3385.761**
DL	1	74146.074**	86108.315**	2480.063**
DQ	1	85161.054**	50168.259**	4291.459**
ERROR	80	192.489	279.526	436.559

[a]DEP = Depth, DL = Depth linear effect, DQ = Depth quadratic effect.

[b]Probability levels for F tests of significance are indicated here.

*Significant at 5% level.

**Significant at 1% level.

Table B-12. Analysis of variance for variable cone index change (after - before) cultivation operations

Source[a]	Degrees of freedom	Mean square
REP	4	3903.735
T. SYSTEM	4	3476.961
ERROR (a)	16	1592.653
POS	1	205.177
T. SYSTEM x POS	4	2567.700*
ERROR (b)	20	881.958
DEP	2	3385.761**
T. SYSTEM x DEP	8	831.885
POS x DEP	2	910.821
T. SYSTEM x POS x DEP	8	575.186
ERROR (c)	80	436.559
RESIDUAL	150	424.072
CORRECTED TOTAL	299	673.932

[a]REP = Replication, T. SYSTEM = Tillage system, POS = Position, DEP = Depth.

*Significant at 5% level.

**Significant at 1% level.

Table B-13. Analysis of variance for variable cohesion before cultivation operations

Source[a]	Degrees of freedom	Mean square
REP	4	1.0852*
T. SYSTEM	4	0.1317
ERROR (a)	16	0.2904
POS	1	0.2888
T. SYSTEM x POS	4	0.1803
ERROR (b)	20	0.1620
CORRECTED TOTAL	49	0.2809

[a]REP = Replication, T. SYSTEM = Tillage system, POS = Position.

*Significant at 5% level.

Table B-14. Analysis of variance for variable angle of internal friction before cultivation operations

Source[a]	Degrees of freedom	Mean square
REP	4	76.553
T. SYSTEM	4	25.568
ERROR (a)	16	25.754
POS	1	0.443
T. SYSTEM x POS	4	22.512
ERROR (b)	20	11.189
CORRECTED TOTAL	49	23.159

[a]REP = Replication, T. SYSTEM = Tillage system, POS = Position.

Table B-15. Analysis of variance for variable cohesion after cultivation operations

Source[a]	Degrees of freedom	Mean square
REP	4	0.402*
T. SYSTEM	4	0.116
ERROR (a)	16	0.094
POS	1	0.145
T. SYSTEM x POS	4	0.077
ERROR (b)	20	0.096
CORRECTED TOTAL	49	0.121

[a]REP = Replication, T. SYSTEM = Tillage system, POS = Position.

*Significant at 5% level.

Table B-16. Analysis of variance for variable angle of internal friction after cultivation operations

Source[a]	Degrees of freedom	Mean square
REP	4	44.759
T. SYSTEM	4	1.731
ERROR (a)	16	18.524
POS	1	16.485
T. SYSTEM x POS	4	59.203
ERROR (b)	20	23.490
CORRECTED TOTAL	49	24.601

[a]REP = Replication, T. SYSTEM = Tillage system, POS = Position.

Table B-17. Analysis of variance for variable cohesion change (after - before) cultivation operations

Source[a]	Degrees of freedom	Mean square
REP	4	1.281
T. SYSTEM	4	0.093
ERROR (a)	16	0.443
POS	1	0.845
T. SYSTEM x POS	4	0.292
RESIDUAL	20	0.233
CORRECTED TOTAL	49	0.393

[a]REP = Replication, T. SYSTEM = Tillage system, POS = Position.

Table B-18. Analysis of variance for variable angle of internal friction (after - before) cultivation operations

Source[a]	Degrees of freedom	Mean square
REP	4	93.977
T. SYSTEM	4	32.873
ERROR (a)	16	58.555
POS	1	11.520
T. SYSTEM x POS	4	53.259
RESIDUAL	20	38.178
CORRECTED TOTAL	49	49.641

[a]REP = Replication, T. SYSTEM = Tillage system, POS = Position.

Table B-19. Analysis of variance for variable moisture content and bulk density change (after - before) cultivation operations in soil sheargraph

Source[a]	Degrees of freedom	Mean squares: Moisture content	Mean squares: Bulk density
REP	4	37.931	0.007
T. SYSTEM	4	14.811	0.036
ERROR (a)	16	25.945	0.024
POS	1	12.550	0.001
T. SYSTEM x POS	4	26.215	0.006
ERROR (b)	20	8.286	0.008
CORRECTED TOTAL	49	18.556	0.015

[a]REP = Replication, T. SYSTEM = Tillage system, POS = Position.

APPENDIX C

Table C-1. Analysis of variance for height of plant in date

Source	Degrees of freedom	Sum of squares	Mean square	F
REPLICATIONS	4	327.35	81.84	7.03**
TILLAGE SYSTEM	4	1698.35	424.59	17.97**
ERROR (a)	16	965.94	60.37	
DATE	1	82601.13	82601.13	2884.51**
TILLAGE SYSTEM x DATE	4	86.01	21.50	0.75
ERROR (b)	20	572.72	28.64	
TOTAL	49	86251.50		

Table C-2. Analysis of variance for variable stand count in date

Source	Degrees of freedom	Sum of squares	Mean square	F	CV
REPLICATIONS	4	18916691	4729173	1.83	2.7233%
TILLAGE SYSTEM	4	938261260	234565315	91.01**	
ERROR (a)	16	41234253	2577141		
DATE	5	48093075	9618615	33.41**	
TILLAGE SYSTEM x DATE	20	13935633	696732	2.42**	
ERROR (b)	100	28783257	287833		
CORRECTED TOTAL	149	1089224170	7310229		

**Significant at 1% level.

Table C-3. Analysis of variance for initial stand count

Source	Degrees of freedom	Sum of squares	Mean square	F	CV
REPLICATIONS	4	1732034.24	433008.56	0.54	4.3%
TILLAGE SYSTEM	4	210806298.64	52701574.66	65.86**	
ERROR	16	12801966.95	800122.93		
CORRECTED TOTAL	24	225340299.84			

**Significant at 1% level.

Table C-4. Analysis of variance for final stand count.

Source	Degrees of freedom	Sum of squares	Mean square	F	CV
REPLICATIONS	4	1921065.04	480266.26	0.95	3.736%
TILLAGE SYSTEM	4	147811989.43	36952997.35	73.59**	
ERROR	16	8034066.16	502129.13		
CORRECTED TOTAL	24	157767120.64			

**Significant at 1% level.

Table C-5. Analysis of variance for corn moisture at harvest

Source	Degrees of freedom	Sum of squares	Mean square	F	CV
REPLICATIONS	4	3.74	0.93	0.92	4.008%
TILLAGE SYSTEM	4	10.42	2.60	2.56	
ERROR	16	16.22	1.01		
CORRECTED TOTAL	24	30.38	1.26		

Table C-6. Analysis of variance for variable yield

Source	Degrees of freedom	Sum of squares	Mean square	F	CV
REPLICATIONS	4	524.08	131.02	2.66	5.181%
TILLAGE SYSTEM	4	1467.40	366.85	7.45**	
ERROR	16	787.39	49.21		
CORRECTED TOTAL	24	2778.88	115.78		

**Significant at 1% level.

Table C-7. Analysis of variance for variable weed

Source	Degrees of freedom	Sum of squares	Mean square	F	CV
REPLICATIONS	4	54691.990	13672.99	3.09	95.924%
TILLAGE SYSTEM	4	117720.485	29430.12	6.62**	
ERROR	16	71063.858	4441.49		
CORRECTED TOTAL	24	242376.333			

**Significant at 1% level.

Table C-8. Values of corn yield, corn moisture, and weed weight

Tillage system	Replications	Corn yield (bu/A)	Corn moisture (%)	Weed weight (lb DM/A)
Fall plow	1	149.60	26.10	96.75
"	2	141.30	26.30	135.45
"	3	146.90	24.50	212.85
"	4	141.80	26.80	0.00
"	5	159.90	27.60	0.00
Plant on ridges	1	138.20	25.50	2592.96
"	2	126.30	23.60	9481.75
"	3	125.30	26.30	4257.11
"	4	147.20	25.40	0.00
"	5	140.70	25.20	0.00
Chisel plow	1	133.90	23.20	1993.10
"	2	128.30	25.10	328.95
"	3	125.80	25.00	193.50
"	4	130.50	25.20	812.72
"	5	144.60	23.40	1935.05

Table C-8. Continued

Tillage system	Replications	Corn yield (bu/A)	Corn moisture (%)	Weed weight (lb DM/A)
Disk	1	121.80	22.90	3146.93
"	2	112.10	24.40	1902.55
"	3	136.40	24.90	1741.54
"	4	117.40	25.50	387.01
"	5	132.80	25.50	1526.55
No till	1	132.70	25.40	2937.40
"	2	137.20	25.30	2641.34
"	3	133.80	24.70	8997.98
"	4	144.50	26.10	2128.55
"	5	135.50	24.10	1685.42

Table C-9. Analysis of variance for corn yields in terms of replications, stand count, weed weight, height of plants and cone index before

Source[a]	Degrees of freedom	Mean square	F
Replications	4	244.42	0.92
Stand	1	471.03	7.11*
Weed	1	152.14	2.29
Height	1	10.41	0.15
CIB_1	1	0.45	0.006
CIB_2	1	6.47	0.09
CIB_3	1	24.17	0.36

[a] CIB_1 = Cone index at 0 - 7 inches depth (before), CIB_2 = Cone index at 14 inches depth (before), CIB_3 = Cone index at 21 inches depth (before).

*Significant at 5% level.

Table C-10. Analysis of variance for corn yields in terms of replications, stand count, weed weight, height of plants and cone index after

Source[a]	Degrees of freedom	Mean square	F
Replications	4	202.06	0.91
Stand	1	689.16	12.44**
Weed	1	97.59	1.76
Height	1	0.11	0.002
CIA_1	1	32.05	0.57
CIA_2	1	28.65	0.51
CIA_3	1	86.62	1.56

[a]CIA_1 = Cone index at 0 - 7 inches depth (after), CIA_2 = Cone index at 14 inches depth (after), CIA_3 = Cone index at 21 inches depth (after).

**Significant at 1% level.